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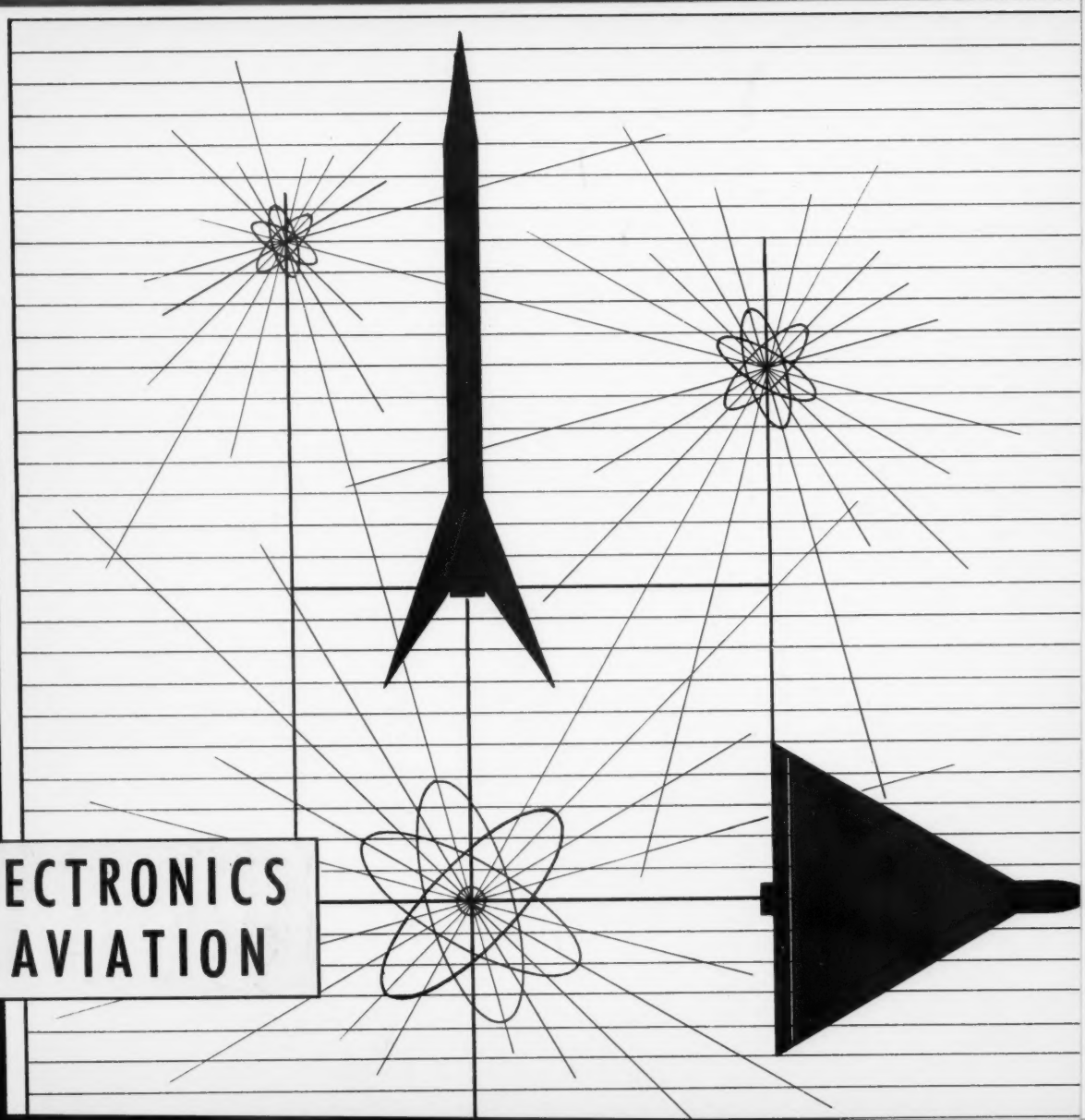
AERONAUTICAL ENGINEERING REVIEW

MAY 1953



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ELECTRONICS IN AVIATION

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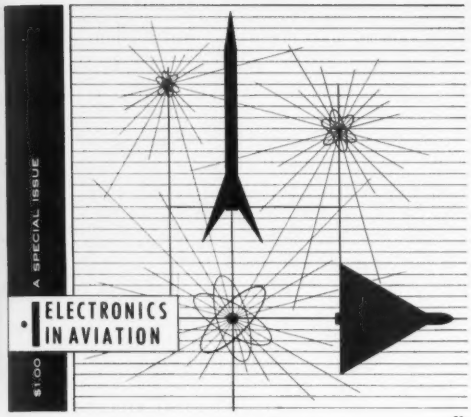

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AERONAUTICAL ENGINEERING REVIEW

Vol. 12 **MAY, 1953** **No. 5**

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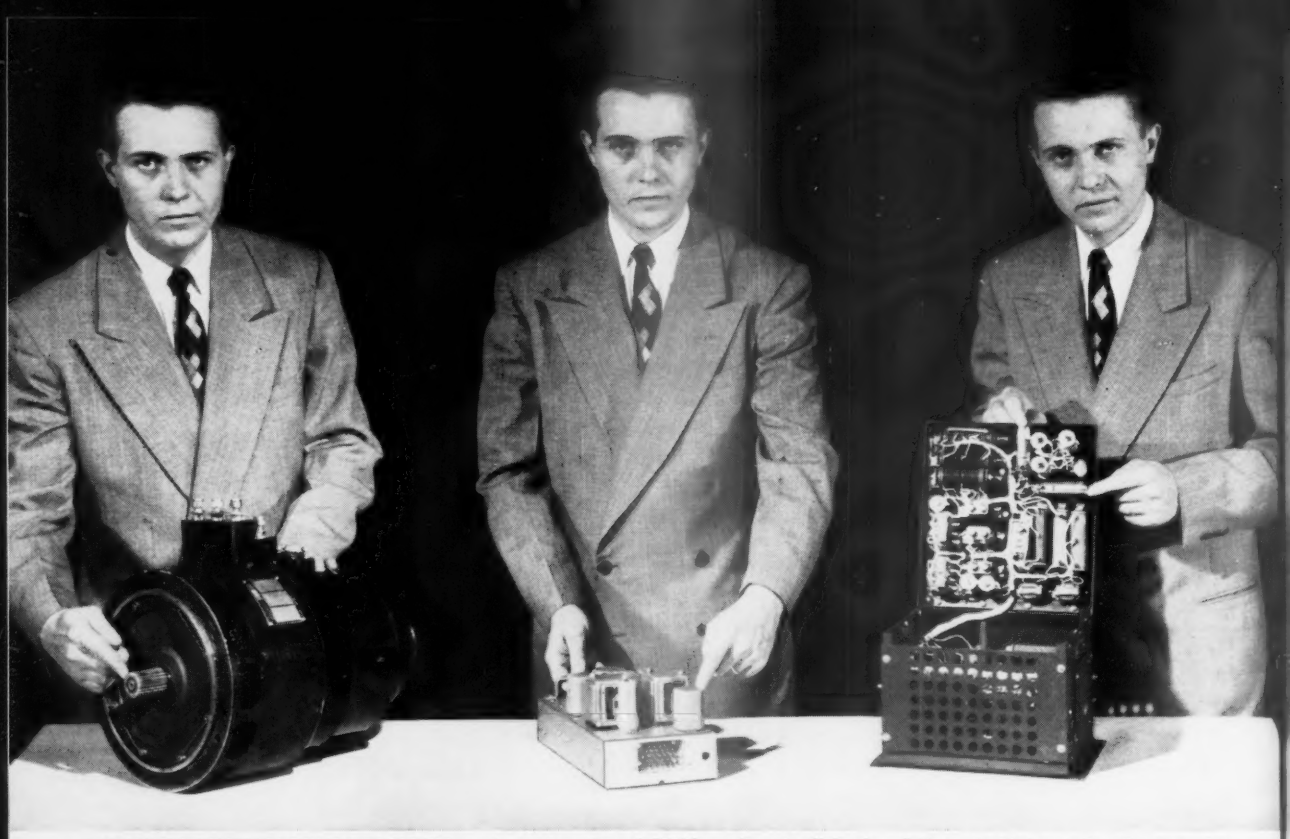

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I.A.S. News Notes

May 1953

HOFF TO PRESENT WRIGHT LECTURE IN LONDON

Dr. Nicholas J. Hoff, Polytechnic Institute of Brooklyn, has been invited by the Royal Aeronautical Society to deliver the 41st Wilbur Wright Memorial Lecture in London, September 14.

* * * * * * * *

NATIONAL TELEMETERING CONFERENCE PROGRAM SET

The theme of the Telemetering Conference being held in Chicago's Edgewater Beach Hotel, May 20-22, will unite the interests of those engaged in performance-test work and those in operational telemetering. A collection of papers, some of which cover only recently declassified techniques, will be presented during the three days of technical sessions. Over 600 persons are expected to attend. Exhibits are a featured part of the show. E. J. Hobson, Director of Stanford Research Institute, will be principal speaker at the banquet on Wednesday, evening, May 20.

* * * * * * * *

FIRST ANNUAL STUDENT COMPETITION IN TEXAS, MAY 6-9

The Texas Section of the I.A.S. is sponsoring a Student Competition being held in Fort Worth, May 6-9. Open to the students of 12 colleges in the general Southwest region of the country, the Competition offers cash prizes ranging from $100 to $300 for the winning papers. An Awards Night Dinner is being held the evening of the 9th. Stories covering the meeting will appear in later issues of the Review.

* * * * * * * *

NEW I.A.S. CORPORATE MEMBERS

Brandt Manufacturing Company, 9784 Bellanca Street, Los Angeles, Calif.
Robert Hewitt Associates, 439 Madison Avenue, New York, New York

* * * * * * * *

NECROLOGY

John Dean Hubbard, Assistant Project Engineer, Chance Vought Aircraft Division, February 2.

John Francis Jacobs, Jr., Director of Electro-Mechanical Engineering, W. L. Maxson Co., New York, April 3.

Flavius Earl Loudy, Chief Engineering Representative of Grumman in the USN Office of BuAero, Nassau, Long Island, New York, March 21.

* * * * * * * *

NATIONAL MEETINGS CALENDAR

May	20-22	I.A.S., A.I.E.E., I.R.E., and I.S.A. Joint National Telemetering Conference, Edgewater Beach Hotel, Chicago, Ill.
July	15-17	Annual Summer Meeting and Honors Dinner, Los Angeles, Calif.
Sept.	7-17	Fourth International Aeronautical Conference, London, England

* * * * * * * *

I.A.S. News Notes (con't.)

CALENDAR OF SECTION MEETINGS

May 5--Hagerstown Section: Hagerstown American Legion, Dinner, 7:00 p.m.; Meeting, 8:30 p.m. "The Aircraft Industry Tomorrow" by Adm. D. C. Ramsey, USN (Ret.) President, A.I.A.

May 6--Wichita Section: Location and hour unknown at press time. "Our New Air Terminal" by Emery Cox, Dir. Wichita Mun. Airport.

May 6-9--Texas Section: Worth Hotel, Fort Worth, Texas, First Annual Student Paper Competition.

May 11--Montreal Section: 401 RCAF Fighter Squadron, Westmount. Meeting, 8:15 p.m. Speaker, Dr. John J. Green, D.R.B.

May 13--Baltimore Section: The Johns Hopkins University, Meeting, 8:30 p.m. "Weapons Systems" by Maj. Gen. D. L. Putt, ARDC, USAF.

May 13--Buffalo Section: Bethlehem Steel Corporation, Meeting, 7:00 p.m. Tour of Bethlehem Steel facilities. Reservations must be made through R. Crisman; Phone NF 7851, Extension, 7120.

May 14--Los Angeles Section: I.A.S. Building, Specialist Meeting, 8:00 p.m. "Secondary Flow in a Cascade of Airfoils" by Hans Eichelberger.

May 14--San Diego Section: I.A.S. Building, Specialist Meeting, 7:30 p.m. Subject: "Stability of Hydraulic Power Control Systems."

May 16--Los Angeles Section: I.A.S. Building, Fourth Annual "Test Hop" (Dance) 9:15 p.m. For tickets, contact I.A.S. Los Angeles office.

May 18--Atlanta Section: Mammy's Shanty Restaurant, Joint SAE-IAS Dinner Meeting, 6:30 p.m. "The Propeller-Turbine Engine" by J. T. Wills, Manager of Sales Engineering, Allison Division, G.M.C.

May 19--New York Section: Grumman Aircraft Engineering Corporation, Social Hour, 7:00 p.m.; Dinner, 7:45 p.m.; Meeting, 8:45 p.m. "Reinforced Plastics in Aircraft" discussed by a panel of 15 experts and introduced by Hiram McCann, Editor, Plastics Magazine.

May 21--Los Angeles Section: I.A.S. Building, Specialist Meeting, 8:00 p.m. "Automatic Cruise Control for Long-Range Jet Aircraft" by J.R. Shull, J.B. Rea Company, and "Digital Techniques in Automatic Flight Control" by Eric Weiss, J.B. Rea Company.

May 21--San Diego Section: I.A.S. Building, Dinner Meeting, 7:00 p.m. Subject and speaker unknown at press time.

May 21--Texas Section: Arlington State College, Arlington, Tex., Specialist Meeting, Hour, subject and speaker unknown at press time.

May 27--St. Louis Section: Forest Park Hotel, Joint SAE-IAS Dinner Meeting, 6:30 p.m. "Development of the Nash-Healey Sports Car" by E. L. Morrison, Chf. Dev. Eng., Nash Motors. Also, films of the 1952 Farnborough Air Show and the High-Altitude Rocket Tests in N.M.

May 28--Los Angeles Section: I.A.S. Building, Social Hour, 5:30 p.m. Dinner, 6:30 p.m.; Meeting, 8:00 p.m. "The Systems Approach to Air Weapons Evaluation" by Maj. Gen. D.L. Putt, ARDC, USAF.

June 3--Toronto Section: Elms Golf and Country Club, Annual Meeting; Dinner, 7:00 p.m. Films to be shown.

June 12--Chicago Section: Glenview Naval Air Station. Annual election of officers. Hours, subject and speaker unknown at press time.

* * * * * * * *

I. A. S. News

A Record of People and Events of Interest to Institute Members

I.A.S San Diego Building Reopened

This Building, Used by an Aircraft Manufacturer for the Past 2½ Years, Now Available Again for I.A.S Functions

THE INSTITUTE OF THE AERONAUTICAL SCIENCES BUILDING in San Diego has returned to the I.A.S. fold after an absence of approximately 2½ years. This building, now a veteran of the present world crisis, was used during this interval as office space in connection with Consolidated Vultee Aircraft Corporation's B-36 modernization program. It is now available as a meeting place for I.A.S. groups, as well as for members of other organizations.

The Institute was fortunate in obtaining once again the services of Mrs. Gayl Mansfield in the position of Secretary. L. E. McCullough has been employed as Building Custodian. For the information of any persons desiring to see the premises or to use the Fleet Foundation Library, the building is open to the public from 9:00 a.m. to 1:00 p.m., Monday through Saturday.

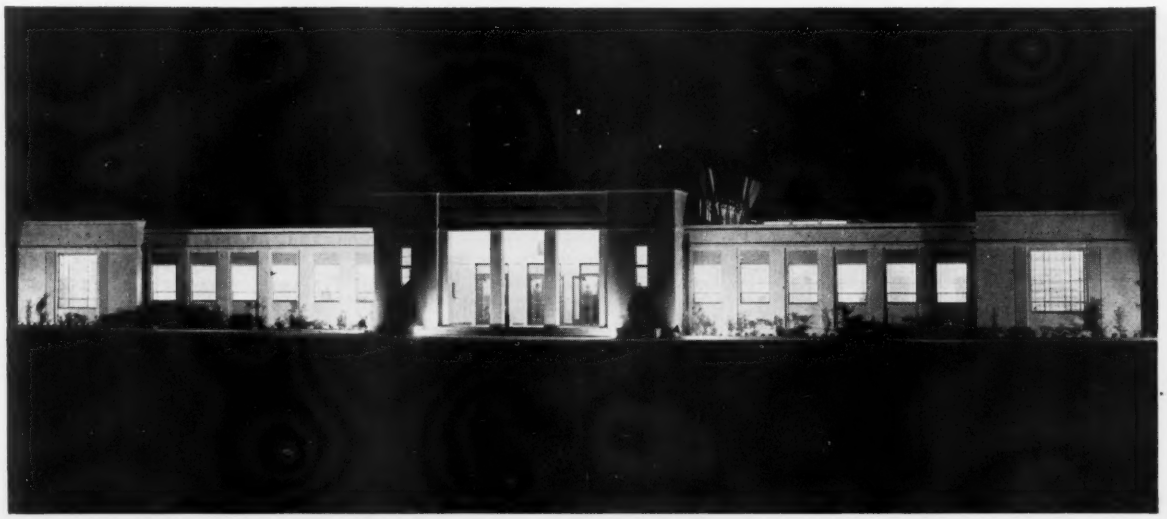
The building is in first-class condition. The interior has been completely refinished, including the installation of asphalt tile over a major portion of the floor surfaces. Minor repairs and alterations have been accomplished.

It will be remembered that in the latter part of 1949, Convair leased the grounds immediately adjacent to the rear of the building for purposes of storage and testing. A short time later, Convair's need for additional space became acute, and the subject of leasing the entire area—the building as well as the grounds—was broached. After due discussion, a lease was drawn up, and in August of 1950 Convair took possession of the property with the proviso that it would be returned to the Institute as soon as circumstances would permit. As is now a matter of record, it was returned this spring.

The history of this building dates back to 1944 when Major Reuben H. Fleet, I.A.S. Associate Member, Founder Member, and Benefactor who was then serving as I.A.S. President, perceived the need for adequate housing facilities for the various activities of the Institute. Under his aegis, the present I.A.S. headquarters building in New York came into being, and the plans for the San Diego and Los Angeles buildings were laid.

In September of 1945, preliminary building plans were approved by the Contributors' Committee for the San Diego Facility of the Aeronautical Sciences. (This committee had been formed several months earlier and was composed of representatives of the contributing aircraft companies.) Two months later, a proposed site for the building was selected. However, the war and rising building costs delayed further progress until 1948, at which time the property was finally secured and the building plans were finalized.

The dedication of the San Diego building on April 29, 1949, was the culmination of approximately 5 years of effort by Major Fleet and the Institute.



Necrology

Mrs. Minta Martin

Mrs. Minta Martin, mother of I.A.S. Honorary Fellow and Benefactor Glenn L. Martin, who in 1917 founded the company that bears his name, died at the Martin home in Baltimore, Md., on last March 14. She was 89 years old.

Eleven years ago, Mr. Martin presented the Institute of the Aeronautical Sciences with a block of stock in his mother's name. This gift formed the Minta Martin Aeronautical Endowment Fund. At the time this gift was being proffered to the Institute, Mr. Martin wrote that it was being made "in commemoration of my mother's sympathetic assistance to and cooperation with me in my aeronautical activities over the past years." This stock now has a value of over $500,000.

Mrs. Martin was always a source of inspiration and encouragement to her son throughout his aeronautical career. In 1908, when Mr. Martin took over an abandoned Santa Ana, Calif., church building in which to construct his first airplane, Mrs. Martin, despite the jeers of well-meaning neighbors and friends, had no doubt of the outcome. "I believed," she said in later years, "that my son could do anything other men did, and usually a little bit better." She demonstrated her abiding faith by repairing with him each evening to the old converted church building and holding in whatever spot it was needed a kerosene lamp that furnished the sole illumination in the building.

In 1912, Mrs. Martin, a former Iowa school teacher, took her first airplane ride—in a plane built and piloted by Mr. Martin. Thus, she became one of the first women to fly and reputedly the first mother to be flown by her son. As the plane was only a single-seater, Mrs. Martin perforce sat on a lower wing spar, her head covered only by a shawl and her feet dangling into space. The flight was made on the Pacific coast and at an approximate altitude of 1,500 ft.

Mrs. Martin made many subsequent flights with her son. But, in 1948, a 40-year-old dream was fulfilled when she and her son made a leisurely 6,500-mile aerial tour of the country in a plane designed and built at The Glenn L. Martin factory. This tour took them to Santa Ana and to other spots important in Mr. Martin's career.

Mrs. Martin is survived by her son, Glenn L. Martin. Her body was flown to Santa Ana for burial.

Aviation Medicine Now Preventative Medicine Specialty

The efforts of the Aero Medical Association to achieve professional recognition of aviation medicine as a specialty in the field of preventative medicine were realized on February 8, 1953. On that date, the American Board of Preventative Medicine was authorized by the Council on Medical Education and Hospitals of the American Medical Association, upon the recommendation of the Advisory Board for Medical Specialties, to grant specialty certification to physicians who are properly qualified in aviation medicine.

This decision authorizes the American Board of Preventative Medicine to award certification in aviation without examination to a "founders' group" in this specialty. Inquiries and requests for applications should be directed to the Secretary of the Board, Ernest L. Stebbins, M.D., 615 N. Wolfe St., Baltimore 5, Md.

When the Council on Medical Education and Hospitals has completed its survey of the academic courses and residencies for postgraduate training in aviation medicine in civil institutions and under federal agencies, it is anticipated that properly qualified physicians may be certified by examination. The Board will continue to grant specialty certification in public health.

National Safety Council's Award Winners

Twenty-four companies active in the aeronautical field participated in a safety contest conducted during the 1952 calendar year by the National Safety Council. According to N.S.C. statistics, the injuries received in this period totaled 1,509, while the total manhours worked were 518,151,000. Using the 1951 calendar year as a comparison, the percentage increase during 1952 in

injuries was a +53, and the percentage decrease in the final 1952 rate was a −5.

For the purposes of the contest, the participating companies were divided into Group A and Group B. The frequency rate during the 12-month period for Group A was 2.82 and for Group B 3.45. The overall rate for the entire contest was 2.91.

Winners of the first three places in Group A were Northrop Aircraft, Inc., of Hawthorne, Calif., with a frequency rate of 1.23; Fort Worth Division of Consolidated Vultee Aircraft Corporation with a 1.49 frequency rate; and Santa Monica Plant of Douglas Aircraft Company, Inc., with a 1.79 frequency rate.

In Group B, Curtiss-Wright Corporation, of Carlstadt, N.J.; AiResearch Manufacturing Company, Division of The Garrett Corporation; and North American Aviation, Inc., of Downey, Calif., took the first three spots. Curtiss-Wright experienced a frequency rate of 0.56; AiResearch, 1.11; and North American, 1.18.

Northrop and Curtiss-Wright, as first-place winners, are to receive appropriate plaques. Certificates are being issued to the second- and third-place winners.

Gas-Turbine Course

An intensive course in gas turbines will be presented at the University of Michigan from June 29 to July 10. This 2-week course has been designed by Michigan's Department of Mechanical Engineering particularly for engineers in the industry, professors contemplating courses in gas turbines, and members of the armed services having a direct interest in gas turbines.

The registration fee of $100 covers the tuition and a set of preliminary notes for the course. Since the number of students in the course is limited to 60, registrations will be accepted in the order of submission.

Registrations and requests for information should be directed to: Frank L. Schwartz, Professor of Mechanical Engineering, 231 West Engineering Building, University of Michigan, Ann Arbor, Mich.

News of Members

▸ **Dr. Hans W. Liepmann** (F.), Professor of Aeronautics, California Institute of Technology, was reappointed to the N.A.C.A. Subcommittee on Fluid Mechanics.

▸ **Dr. Frank E. Marble** (M.), Assistant Professor of Jet Propulsion and Mechanical Engineering, California Institute of Technology, was renamed to the N.A.C.A. Subcommittee on Combustion.

▸ **Dr. Clark B. Millikan** (H.F.), Professor of Aeronautics and Director, Guggenheim Aeronautical Laboratory, California Institute of Technology, was reappointed Chairman of the Subcommittee on Fluid Mechanics and a Member of the Committee on Aerodynamics, N.A.C.A.

▸ **John K. Northrop** (F.), who retired last November as President of Northrop Aircraft, Inc., has been retained on a part-time basis as a Consultant to the President of The Garrett Corporation. He is undertaking a military product survey for AiResearch Manufacturing Company in an effort to determine military accessory requirements several years hence.

▸ **Dr. Ernest E. Sechler** (A.F.), Professor of Aeronautics, California Institute of Technology, was reappointed to the Subcommittee on Aircraft Structures, N.A.C.A.

▸ **C. Glen Williamson** (M.), resigned his positions as President and Director of Kellett Aircraft Corporation. This was effective February 10, 1953.

AERONAUTICAL UNIVERSITY PRESIDENT

Kenneth L. Burroughs (A.F.) has been elected President of The Aeronautical University, succeeding Lewis M. Churbuck who remains as Chairman of the Board and Treasurer. Mr. Burroughs, who has been associated with the university since its founding in 1929, was previously Vice-President.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of I.A.S. members. All members are therefore urged to notify the News Editor of changes as soon as they occur.

Harold Andrews (T.M.), Graduate Student in Aeronautical Engineering and Instructor in Engineering Materials, Cornell University. Formerly, Assistant Research Mechanical Engineer, Cornell Aeronautical Laboratory, Inc.

Curtis L. Bates (M.), Assistant Director of Engineering, Ryan Aeronautical Company. Formerly, Chief, Mechanical Design, Northrop Aircraft, Inc.

Major William S. Dawson, U.S.A.F. (A.M.), Commanding Officer, 1300th Student Squadron, Air Resupply and

(*Continued on page 102*)

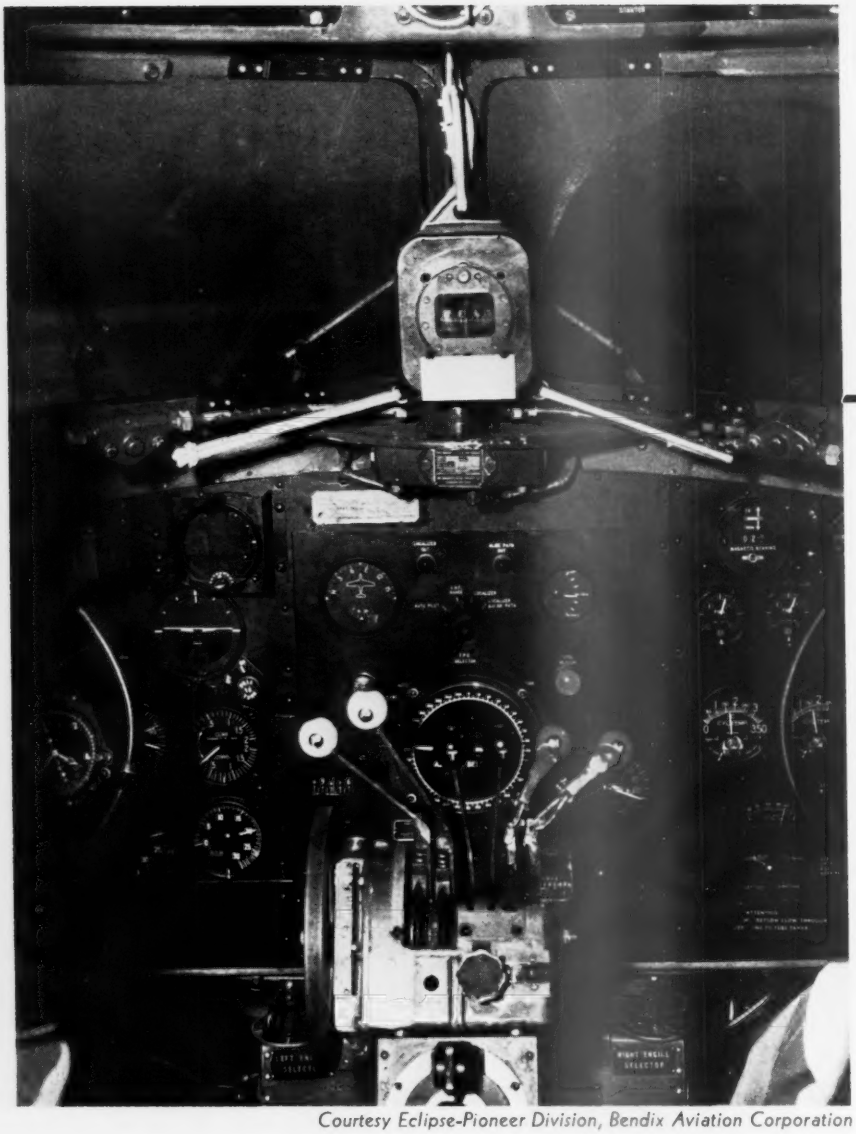
National Telemetering Conference

Edgewater Beach Hotel, Chicago, Ill. *May 20–22, 1953*

This conference, at which papers on mobile and point-to-point telemetering will be presented by leading international authorities, is being sponsored by the American Institute of Electrical Engineers, the Institute of the Aeronautical Sciences, the Institute of Radio Engineers, and the Instrument Society of America.

Engineers and scientists from all parts of the free world are expected to attend. These persons will represent many organizations in government and private industry which are concerned with telemetering.

For information relative to registration, please address all correspondence to: W. H. Wickham, Commonwealth Edison Company, 2233 South Throop St., Chicago 8, Ill.



Courtesy Eclipse-Pioneer Division, Bendix Aviation Corporation

The potentialities of automatic approach are demonstrated here as an Eclipse-Pioneer electronic Autopilot and Flight Path Control bring a DC-3 in on a glide-path for landing on a runway barely discernible through rain and mist of left windshield. At approximately 300 ft. altitude, the pilot obligingly stepped out of the cockpit to let the photographer snap this picture.

Editorial

Electronics vs. The Human

This is the third in the series of special electronic issues of the REVIEW. It is also the third year that the Institute has devoted one entire day of its annual meeting to the subject of Electronics in Aviation. We are happy to report that considerable progress appears to have been made in this field in the meantime.

No longer does every electronics engineer view the airplane as a neurotic patient whose only cure depends upon his patent medicines and prescribed crutches. Nor, do most aircraft designers continue to look upon electronic equipment as an assortment of temperamental black boxes intended and destined to ruin his airplane's performance. Much has been accomplished in the way of bringing about a meeting of the minds and a mutual understanding and appreciation of the problems.

The Institute is proud of the part it has played—and will continue to play—in this connection.

Electronics has given us the ability to achieve speeds, performances, and a degree of safety in flying which go far beyond the powers of the human pilot alone. Reliability and versatility of the equipment have constantly improved. Through miniaturization and substitution of materials and methods, the electronics industry has developed products that are entirely compatible with good airplane design and performance requirements.

As yet, however, nobody has come up with a gadget that "thinks." Until they do, it seems apparent that the human pilot and crews will always be with us on passenger-carrying aircraft.

We can, and have, designed equipment that can solve nearly any equation or perform almost any kind of job. Given a predetermined set of facts or a specific thing to do, a well-designed electronic-mechanical gadget can do it more consistently—and usually faster and more accurately—than the human. Its primary weakness seems to rest in the fact that once committed (by human design) it can only do what it was supposed to do in the first place.

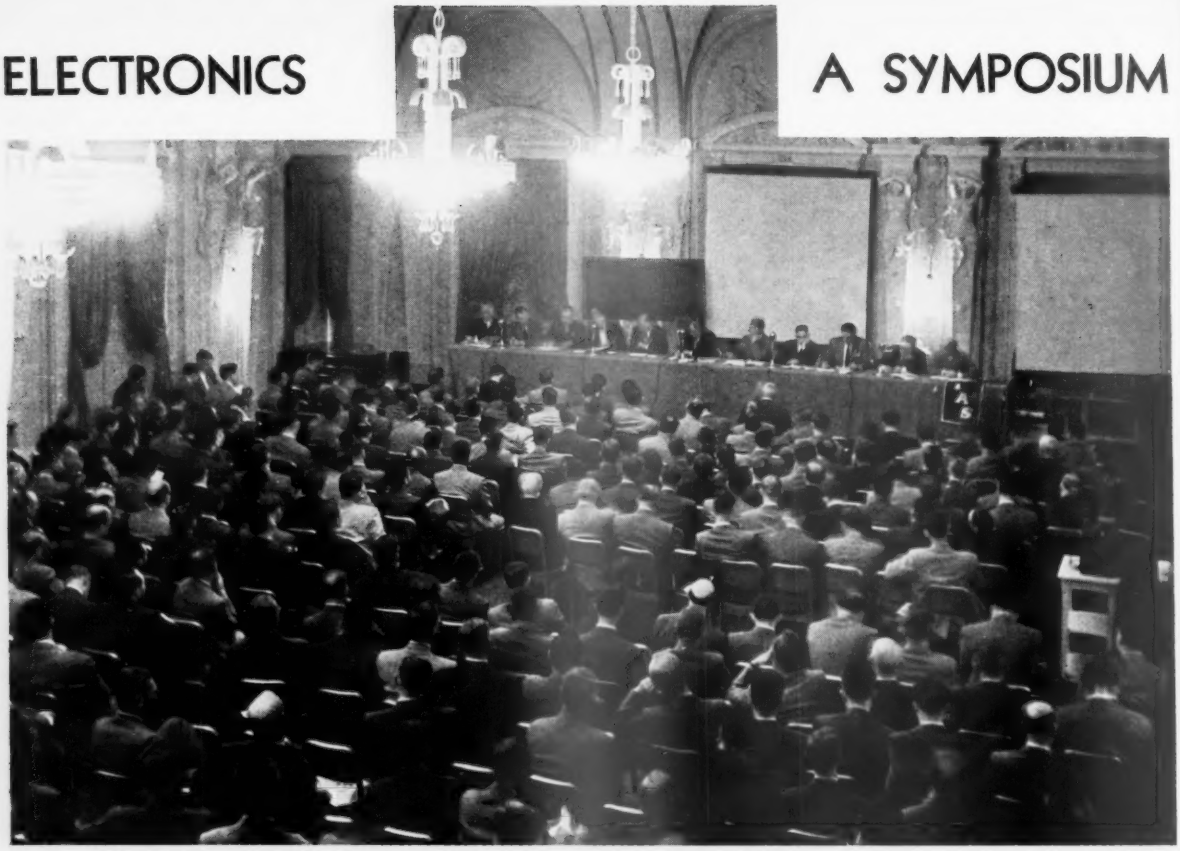
There are circumstances under which such perfection of performance might well be disastrous. These are the times when human judgment is nice to have around.

Recognition of these facts gives both the electronics engineer and the airplane designer a common ground upon which to work. Reliable automatic controls that ease the physical and mental strain of the human pilot are much to be desired in passenger-carrying planes. Complete automaticity in guided missiles and pilotless aircraft is an undeniable necessity.

Perfection of the latter will unquestionably benefit the former. But, as of today, nobody is quite ready to "go along for the ride" on that pilotless flight from New York to London.

The pros and cons of these tenets formed the basis of discussions at the Institute's recent Electronics Symposium. What the experts had to say on these subjects makes the following pages interesting and worthwhile reading. W.A.S.

ELECTRONICS — A SYMPOSIUM



ELECTRONIC CONTROL AND STABILIZATION OF AIRCRAFT

Chairman

Edward Warner

Panel Members

Operational Aspects

Rear Adm. G. B. H. Hall, Commander, Fleet Air Wings, Atlantic Fleet, N.A.S.

Capt. W. A. Jensen, A.N.T.C. Division, Air Transport Association

Brig. Gen. Benjamin S. Kelsey, Deputy Director, Research & Development, U.S.A.F.

E. W. Pike, British Overseas Airways Corporation

Electronic Aspects

Paul R. Adams, Director, Aviation Development Laboratory, Federal Telecommunication Laboratories

B. H. Ciscel, Minneapolis-Honeywell Regulator Company

C. S. Draper, Professor, Massachusetts Institute of Technology

Aerodynamic Aspects

Harry J. Goett, Chief, Full-Scale and Flight Research Division, N.A.C.A.

A. L. Klein, Design Consultant, Douglas Aircraft Company, Inc.

W. F. Milliken, Jr., Manager, Flight Research Department, Cornell Aeronautical Laboratory, Inc.

EDITOR'S NOTE: *This symposium, presented at the Institute's Twenty-First Annual Meeting in New York, January 28, 1953, was jointly sponsored by the Institute of the Aeronautical Sciences, Institute of Radio Engineers, Institute of Navigation, and Radio Technical Commission for Aeronautics. In addition to the panel of experts, many members of the listening audience (which at times numbered as high as 400 to 500 people) participated in the open discussions. The symposium continued throughout a full afternoon and evening.*

Because of its length and the volumes of recorded discussions, it has been necessary to excerpt only the more salient points for publication purposes. Dr. Warner's introduction of the panel members and much of the humorous repartee (which added so much to the enjoyment of the audience) have, of necessity, been omitted.

Introduction

By
Edward Warner

My job here is somewhat that of the property man in the classic Chinese drama, who sets the stage as unobtrusively as possible, then retires into the background, and lets the cast hack away at one another—and then the audience at them. . . .

The title of this symposium is "Electronic Control and Stabilization of Aircraft." The subject is to be treated primarily in an operational sense to answer such questions as: "What is now being done by automatic control?" "How useful is it to the operator?" "How satisfactorily is it being done?" "What else would we like to do?" "What benefits could be expected if we did it?" "What are our chances of doing it?" "How should we set about it?". . .

All of these questions, and others that might be framed along the same lines, are essentially questions of the mutual influence among the three groups who represent the operational, electronic, and aircraft design aspects of the subject under discussion here today. . . .

There will first be a brief initial statement by each member of the panel, bringing out points that seem to him to be particularly significant. . . . After the initial statements will come the discussions—both within the panel and from the audience. . . .

I should like to make one other point before inviting Captain Jensen to speak first—that is, that this discussion, obviously, covers a considerable time range. It covers what is being done at the present time and what might be done in the immediate future. It also covers some of the possibilities extending perhaps 10 or 20 years ahead. . . . Captain Jensen, will you open?

Operational Aspects

By
Capt. W. A. Jensen

In leading off this discussion, I would first like you to know that it is a privilege for an air-line pilot, such as myself, to be able to participate in a discussion such as this. It is unfortunate that we air-line pilots don't have the time, or at least don't take the time, to take part in more meetings and discussion with the engineers so that we can get to know you better and have a freer exchange of ideas between us.

The air-line segment of the aviation industry has but one final reason for being, or one final purpose—that is, to transport an item (either passengers, mail, express, or freight) from its point of origin to its intended destination, or from point "A" to point "B." This transportation should be accomplished, first of all, safely. It must be done efficiently. In the case of passengers, it must be done comfortably. For the air line to succeed, it must be accomplished at a profit.

It is our job as pilots to serve the passenger or shipper directly by satisfying these requirements as best we can.

In turn, many other people or groups of people are serving us. One of these groups is the engineering group, which provides us with the tools of our profession—the aircraft and all its related equipment.

Consequently, it becomes necessary for the engineer to become thoroughly familiar with our needs so that he has a starting point from which to proceed. From then on, discussions are in order between the pilot and the engineer to determine how well the needs can be and are being met and, when necessary, what compromises to make.

Relating all this to the question at hand—that of automatic flight control—I think that the needs of the air-line pilot are not too difficult to outline. They relate directly to the basic functions of an air line mentioned a moment ago—the functions of transportation from "A" to "B" safely, efficiently, and comfortably.

Safety is always the first consideration. An automatic pilot or any individual element of automatic control must first of all contribute something to the safety of flight rather than detract from it.

Air-line pilots are the people probably most interested in this point. We don't want that growth curve that you heard about to reach up and kick us. We are most particular about what gets into our cockpits. Take the copilot for example.

The successful copilot undergoes a continuous succession of elimination processes, both technical and physical processes, from the time he begins his flying career as a student pilot, either as a civilian or military student pilot, until the day he finally finishes his copilot training

Courtesy Sperry Gyroscope Co

DC-6 cockpit of Aero Lineas Argentinas showing installation of an A-12 Gyropilot.

and takes his first air-line trip as copilot. We can't tolerate anyone in the cockpit who will ever, for example, unconsciously kick a full left rudder.

I think the inference is obvious. An automatic pilot becomes a counterpart of a pilot. If an automatic pilot should, in error, apply full left rudder, it is in the same category as a copilot doing the same thing.

The automatic pilot must also undergo a thorough and corresponding check-out period that is equally as thorough as that of a copilot check-out period, and if a defect develops later, it must be eliminated until the defect is corrected.

In short, the automatic pilot must be safe. As one pilot told me last week; "The automatic pilot on this plane is probably 95 per cent reliable, but I don't use it for automatic approaches because of that remaining 5 per cent." The reason he didn't use the automatic pilot and its coupler for automatic approaches is because of the other 5 per cent.

Perhaps his percentages will not stand up against statistics, but the point that I want to emphasize is that the air-line pilot's first requirement of an automatic pilot is the reliability that is essential to safety. In fact, I think it is an accepted fact that, in general, we expect and require more reliability out of a mechanical element than the human element that it replaces.

So much for safety. The second point that I mentioned was efficiency. Efficiency as related to air-line travel is the sum total of numerous factors, among them speed, schedule reliability, cost, etc. These factors are generally of more direct concern to the air-line operator than the pilot, although indirectly they are of pilot concern, for as the air line prospereth, so prospereth the pilot. Actually, I think you would all be agreeably impressed if you were able to see first hand how concerned most pilots are with providing efficient, as well as safe, transportation.

The third requirement was for comfort of flight. Speed may be a primary salable feature of air travel, but comfort must be a close second. Consequently, a successful automatic pilot must control in such a manner that the resultant flight in conditions of turbulence will be as smooth or as comfortable as manual flight—preferably more so.

In that connection, I have heard pilots mention the fact that they are concerned whether sufficient emphasis or sufficient research has been placed on the question of whether automatic flight and automatic altitude control puts stresses on the aircraft air frame of a higher degree than that which would be imposed by manual flight under the same conditions. Maybe we can get more information on that as the discussion continues.

It would be logical at this point to question whether an air-line pilot has need for an automatic pilot in the first place, and if so, why and for what portions of the flight?

In my opinion (and it should be noted here that these are necessarily my opinions throughout, and not necessarily those of the Air Line Pilots Association or any other organization) automatic pilots for at least some, if not all, types of aircraft are needed both for the en route and approach portions of flight. You will probably hear more from Mr. Pike concerning the jet operations. I am concerned with piston-engined aircraft.

En route, the function of the automatic pilot is to increase the safety, efficiency, and comfort of the flight by providing a full-time attitude and altitude control. Without an autopilot, the air-line pilot's attention is divided among a multitude of responsibilities, of which attitude and altitude control are only two.

The other day, I counted up the various controls, switches, and indicators facing me in the cockpit of the Convair which I fly. Remembering that this is only a two-engined airplane and that there are many controls and switches behind the pilot's seat, it might be interesting for you to know that I counted approximately 50 controls, 85 switches, and about 90 indicators.

Of course, we don't use all of them all the time, but there are enough that are used all of the time to take considerable attention without even considering such important duties as keeping watch for other air traffic, making radio reports, navigating, etc.

A good reliable automatic pilot—I mean one that does what you tell it to do—should certainly be able to contribute to the safety of flight by releasing a portion of the pilot's attention from flight control to the duties just mentioned.

A reliable autopilot should also be able to increase the safety and efficiency of an approach. Safety would be increased again by the ability of an autopilot to devote full time to the attitude and altitude control of the aircraft. The efficiency should be increased by allowing improvement of schedule reliability.

I realize that these have been rather general statements and that you are interested in more specific details, but it is hoped that these questions will be answered in the discussions to follow and that the foregoing will provide a common basis for these discussions.

Operational Aspects

By
E. W. Pike

My remarks are almost entirely related to the effect on our planning of the introduction of commercial jet aircraft. As a result of our experience so far in operating a commercial jet aircraft on scheduled long-distance flights, we have found a real need for (a) accurate airspeed control, coupled with the autopilot; (b) accurate engine power control by control of speed, fuel flow, or by some other means.

Both of these requirements emanate from the necessity for controlling high-speed flight for maximum economy within much closer limits than we found necessary for earlier transport aircraft and because we find flying to these closer limits manually is, in practice, a virtually impossible task for the crew members.

For instance, movement in the cabin of the Comet, or turbulence, affects the optimum attitude causing speed variations of 20 m.p.h. or so, detracting from the eco-

nomic operation so highly desirable in jet aircraft and causing strain on the crew who must continually try to counteract these effects.

An air-speed lock, maintaining air speed within 2 or 3 knots, appears to be the order of the operational requirement. It may be noted that in the Comet a change of attitude of 1′ of arc from the optimum in the cruising condition is, roughly speaking, equal to a loss of 1 knot in air speed. Also, a decrease of 1 per cent in r.p.m. corresponds to about 13 knots in air speed.

We find the general aerodynamic qualities of the Comets satisfactory. We believe that they will lend themselves to the use of an adequate automatic speed control system when one is developed and available.

We also believe that more accurate automatic fuel flow control (with, of course, the safeguard of a manual override for emergency use) is going to become increasingly important for the economical operation of jet aircraft.

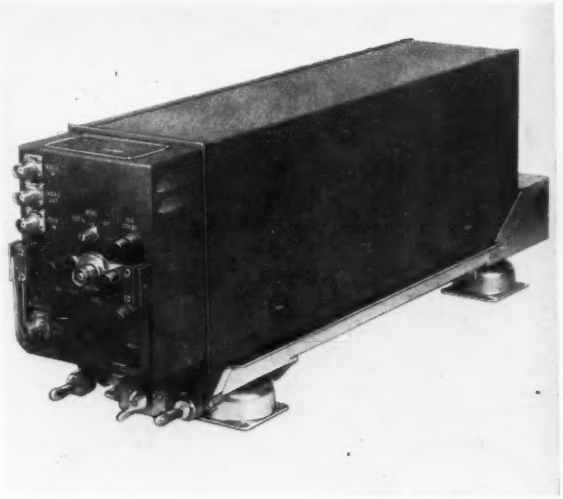
With regard to the approach and landing problem, although certain characteristics of the Comet differ from those of piston-engined aircraft, our operational minimums are about the same as for the latter, and, of course, all air lines are seriously concerned with the safe reduction of minimums to reduce delays and diversions.

Ideally, for commercial reasons, we would like reliable, fully automatic control from the beginning of final approach until the aircraft reaches the apron. However, we recognize that automatic control is a means and not an end, and although our final objective is all-weather operation, there is an economic limit to the price we can afford. The possibilities of an alternative means, such as FIDO, must not be ignored.

In any event, we must continue to rely on a human pilot for "fail-safe" purposes. Therefore, improvements in aircraft handling qualities are most important if he is to fulfill this function with safety at low altitudes. As examples of these desirable improvements, I would suggest approach speed reduction, immediate response to all control movements affecting both engines and aircraft, greater stability in speed and attitude, better flare characteristics, closer attention to cockpit cutoff effect, reduction of the ballooning when setting landing flap, and a smooth rapid transition from the approach to the missed approach configuration. These all merit serious attention in the design stage.

Introducing larger aircraft of greater mass will, in itself, increase the difficulty on final approach, since the angular accelerations acceptable must be limited by the effect on both passengers and pilots and by effects of dynamic similarity. Therefore, because rates of roll and yaw go down, more time will be required to correct any given displacement error using the approach system.

The Comets are fitted with Sperry Zero Readers, but because of the comparative lack of ILS ground installations on many of our routes and also ground equipment unreliability in other cases, our experience so far with ILS approaches in service is rather meager. We are hoping that this unsatisfactory situation will soon improve and that lower operating limits can be safely established. We are interested in improved automatic couplings but have as yet no experience in using them on the Comet.



Courtesy Hazeltine Electronics Corp.

Model 1800 Airborne Distance Measuring Equipment Interrogator.

Generally speaking, we are asking that (as with Comet I) the future aircraft we order have reasonable stability in all normal flight conditions and configurations and in emergency conditions. We prefer to leave speculation on difficulties presented by certain trends to aircraft designers and research organizations.

In summary, we want improved stability, improved engine power control, and quick recovery from attitude changes. Secondly, we want improvements in the implementation and reliability of ILS and improved coupling methods in the aircraft.

Further requirements, admittedly tough but of some importance in high-speed flight, are (1) automatic warning of severe vertical gusts far enough ahead of the aircraft so that avoiding action can be taken and (2) automatic air-to-air collision-warning and -avoidance.

Finally, the increased tempo of jet operations necessitates every effort being made to streamline functions and reduce the pilot's work load so that he becomes more a monitor of functions (with due regard to fail-safe requirement) and less of a manipulator of controls and so that he is able to arrive at the correct operational decisions with comparative ease and rapidity.

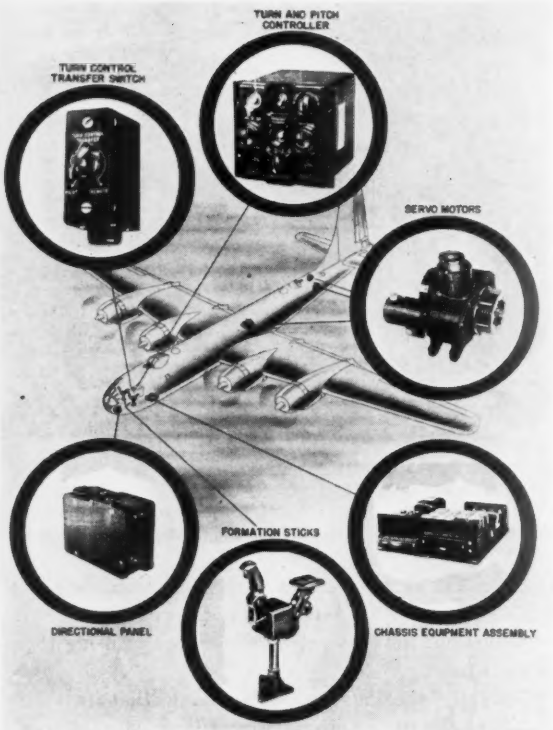
Operational Aspects

By

Brig. Gen. Benjamin S. Kelsey

There is one facet of this operational problem which may be an advantage. Machinery fails too, and once in a while in automatic operations you will get an accident. It might be convenient at times to write down on the accident report not that the pilot pulled a boner but that the machinery made a mistake!

We illustrated this in an automatic flight machine that we had arranged for a preprogram completely



Courtesy Minneapolis-Honeywell Regulator Co.

An earlier model, showing the components and installation of a complete Honeywell Electronic Autopilot for military bomber aircraft. Two gyros, the Rate Gyro, which controls rate-of-turn, and the Vertical Gyro, which controls roll and pitch of the airplane, are mounted in the Chassis Equipment Assembly. The Turn and Pitch Controller is mounted in the cockpit and is the pilot's master control for the entire system.

automatic flight. Having energized the equipment, the sequence got out of step; the power went on, and the gear retracted before the brakes released.

The Air Force is now talking in terms of systems. This is a new approach to try to get across the implications inherent in building anything for a military operation which involves more than any one particular package.

We speak now of bombing systems, which include navigation and means for locating targets, determination of the point of releasing bombs, and all the other combinations and components that go into putting the bomb on the target. This is a bombing system. It is included in what we now call a weapons system, which happens to be an aerodynamic package that includes this component and others. This aircraft is part of another system and includes ground environment and all the supporting services.

This systems approach means that there is less and less differentiation between those things that we normally associate with aircraft design and those things we associate with gadgetry. We find little distinction between equipment that has been taken aloft and equipment left on the ground. We make less and less distinction between things that are called Naval systems and things that are called military systems. We find that Naval provisions are included at the present time in bombing systems.

Going on from there, we have a background of sensing versus actuation. This is a technical phraseology. It means that there are a lot of impulses available which have to be interpreted and applied to certain mechanisms in the aircraft system.

In making a completely automatic flight a few years ago, we brought these things to a "breadboard." We picked up all the things that might be considered sensing elements—time, air speed, attitude, and such things as "real time" scales or "relative air."

That is one of the indications, for instance, which you can't use conveniently with a pilot. Yet, you would like to know what angle of attack is, because this is the critical item—not the air speed. But you have no way of using it with this automatic arrangement. It is possible to bring in many of these other sensing elements.

On the other side of the board, we put in everything, such as pulling up the gear, setting the power, etc. In between, we had the problem of programming and connecting these things across. In this gap we put what we called a master sequence selector.

We found that in hooking these up there were a great many sensing elements that could be hooked directly to operating elements by passing the sequence arrangement.

If you apply this, you will find that there are a great many places in which we have a large degree of automatic flight today. Whether it is electronic or mechanical is not so important. Most of it can be done electronically, and some of it can be done hydraulically. It makes little difference in this part of the discussion. Much of it we accept.

The jet engine is so complicated that all of the controls must be built by the engine manufacturer. So the operation is not confused by all these operating schedules, which is a backlog and inheritance in the past, on which man has insisted that all the knobs be brought up for his use. The fact that he can't use them properly is beside the point.

If we take some of these compartmented things like the bombing system, for instance (we have long since hooked up directional control with automatic pilot and bomb release), we know that we get a better performance out of this than if we try to present it, have the pilot interpret it, and then put it back into autopilot or manual flight.

Automatic flight can be fed in more directly than you can feed it through the pilot. We found this out on some automatic approach tests with the B-29's. On one of the initial tests or orientation flights, the pilot inadvertently didn't switch off the automatic coupling soon enough, and the plane made a perfectly good and complete instrument landing—which was something the pilot never had been able to do manually.

In some of our higher speed approaches, we found that power control for "fighters" with a plotted course and computed course requires a precision of control be-

yond manual capability. For some of these reasons, obviously, we are going, in military applications, to a high degree of automatic control and automatic stability.

The point I would like to make is that today we have available a great deal of automaticity. In the future there are a great many places where we could apply this. But today we have a difficulty in that many of the elements are not compatible; they are compartmented—unrealistically, in many cases.

It would seem that it would be worth while to work today on making elements compatible and making them interconnected. We can then utilize immediately those elements that are now available and apply future developments as rapidly as they become available.

Operational Aspects

By
Rear Adm. G. B. H. Hall

The Navy has an intense interest in automatic flight. It is particularly interested in such features of automatic flight which will permit us to do our current job better and more economically.

The interest of the Navy in this regard was shown as far back as 1922, when experimental remote control work was conducted, using a World War I training seaplane, at Dahlgren, Va.

Since that time, the Navy has assisted in much of the great progress that has been made. We have conducted tests with instrument landing systems in the 1930's. We have sponsored the widespread use of ground control approach; we have pioneered in night-fighter and night-attack work during the war and have cooperated with the other services and with civilian aviation in setting up many national standards.

We are using regularly remotely controlled aircraft for gunnery training, and we have attained a degree of success in our guided-missile work. We feel, however, that much remains to be done before we can depend fully on truly automatic methods of flight control. These methods, which include many electronic techniques and component equipment, must undergo comprehensive tests, extensive flight evaluations, and then thousands of hours of service experience before we can accept them without reservations.

With regard to flight in critical weather, the Navy can now, and does, fly in any weather that is humanly possible, using current equipment. We should like to do this with less restriction in peacetime and less loss of material and men in time of war. Specifically, we would like to see great improvements both in our cockpits and in the terminals that we are obliged to use.

Economy of operation is an important factor to us. We are concerned with economy in fuel, in material, and in the lives of men. It is obvious that the less gas we waste on take-offs, our en route errors, and in stack-ups, the more time we will have and the fewer airplanes we will need to carry out our defensive and offensive missions—our sole reason for existence.

Navy planes, as well as those of other services and civilian planes, require stability of plan form for carrying out their jobs. We are concerned with crew comfort because it effects their efficiency of operations under tense and arduous conditions.

Efficient traffic control, whether it be of patrol planes, carrier planes, or logistic support planes, is vital. Traffic control is an important element of the principle of economy of employment.

With regard to flight planning, such improved features of automatic flight which will improve our advantages of mobility and flexibility in deployment and action are welcomed by the Navy. We look forward to the time when the Naval pilot can pay much less attention to the elaborate system of instruments and more attention to the combat or military features of every flight. Yet, at the same time, the provision of automatic control must allow for failures and for the saving of the aircraft by conventional means. Our inclusion of complicated equipment cannot be allowed to increase heavily the maintenance and logistic support problems that are now straining our training and operational commands.

From the operational point of view of the Navy, we must strive continuously to balance between what we want developed and what we can actually put in the service or field every day for practical use. The adoption of all new devices must be considered from many angles but particularly from the capability of men we have now and men whom we would employ in time of war to handle them.

There is a vast amount of thinking and work going on nationally and internationally on the subject of automatic flight. The Navy is particularly impressed by the human engineering approach being made by many organizations to solve the various aspects of the remaining problems. We believe, however, that we will be obliged to go through many stages of approximations before complete automatic flight is solved to the extent where we can assuredly take off, navigate, operate, and land, consistently, aircraft carrying human operators. We must keep in mind the principles of simplicity and reliability throughout all of these approximations. We also are concerned with the weight-growth factor of all our aircraft.

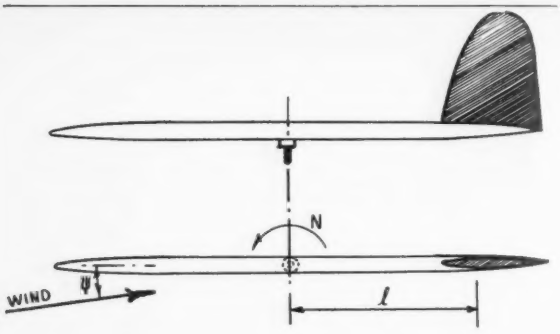
The Navy's carriers, our experience in seaplanes, our development of guided missiles, and our continuous exercises in many parts of the world, will undoubtedly contribute toward the systematic solution of automatic flight for use by both the military and civil aeronautics.

Aircraft Design Aspects

By
W. F. Milliken, Jr.

In the following statement I should like to introduce the subject of artificial stability into the panel's discussion.

Artificial or "ersatz" stability—of which the yaw damper is one example—utilizes many of the same com-

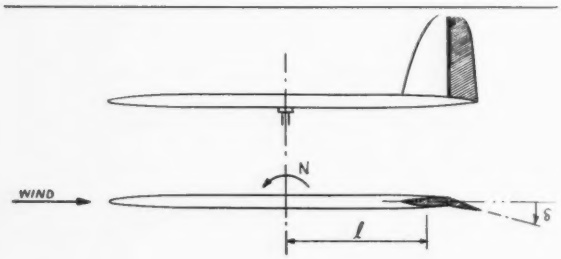


$$N = \frac{dC_L}{d\psi}\psi q S l$$

$$\frac{dN}{d\psi} = \frac{dC_L}{d\psi} q S l$$

= STATIC DIRECTIONAL STABILITY

Fig. 1

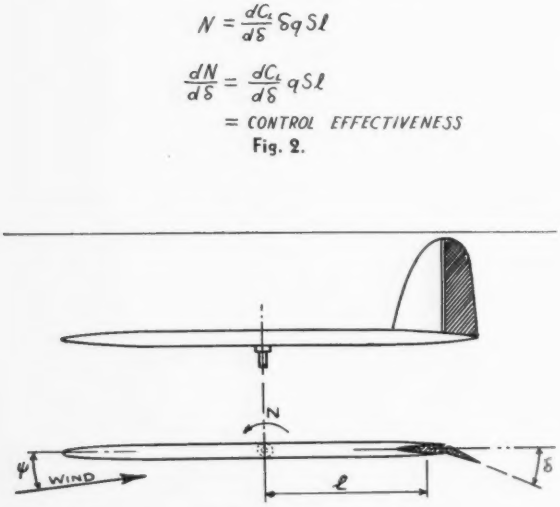


$$N = \frac{dC_L}{d\delta}\delta q S l$$

$$\frac{dN}{d\delta} = \frac{dC_L}{d\delta} q S l$$

= CONTROL EFFECTIVENESS

Fig. 2.



IF CONTROL MOVED PROPORTIONAL TO ψ

$$\delta = K\psi$$

$$= \frac{d\delta}{d\psi}\psi$$

THAN,

$$N = \frac{dC_L}{d\psi}\psi q S l + \frac{dC_L}{d\delta}\frac{d\delta}{d\psi}\psi q S l$$

$$\frac{dN}{d\psi} = \frac{dN}{d\psi} + \Delta\frac{dN}{d\psi}$$

WHERE,

$$\Delta\frac{dN}{d\psi} = \frac{dN}{d\delta}\cdot\frac{d\delta}{d\psi}$$

= ARTIFICIAL CONTRIBUTION TO STATIC DIRECTIONAL STABILITY

Fig. 3.

ponents, such as servomotors, amplifiers, etc., as fully automatic control systems and is, hence, frequently confused with these devices or systems. There are, however, practical distinctions between artificial stability and conventional automatic control, and these will now be outlined.

In the first place, the objective of artificial stability differs from that of automatic control. Whereas the fundamental job of complete automatic control is stabilization and guidance of the aircraft relative to some external frame of reference axes—such as those fixed in the earth, for example—artificial stability seeks stabilization in reference only to airplane motion parameters such as yawing, rolling, or sideslip velocities and, hence, stabilizes in reference to the relative wind or motion created by the aircraft itself.

In some respects, artificial stability may be directly analogous to the aerodynamic stability designed into the aircraft and may be dependent upon its surface areas and other geometrical features.

The simplest observable difference between artificial stability, as here defined, and automatic control is that the human pilot retains his conventional function in the former—i.e., supplies overall guidance through the normal flight controls. In short, artificial stability is designed to improve the handling qualities of the manually flown aircraft.

The potentiality of artificial stability—at this juncture in the evolution of electronics and aircraft—is that it provide a means of vastly improving flying qualities for the performance of tasks now marginal or impossible with the aerodynamic aircraft, without going to completely automatic controlling systems. Mr. Goett will undoubtedly amplify this thought later.

To clarify these ideas further, I would ask your indulgence in illustrating these distinctions by use of an old-fashioned weathervane. As an example, I should like to show how the static directional, or weathercock, stability may be enhanced artificially.

Fig. 1 shows a simple weathervane producing static directional stability proportional to yaw angle. The slope of the yawing moment curve is defined as this stability.

Suppose now that control of the yawing motion of the vane is desired—namely, control of the angle of yaw. A movable rudder may be installed which has a 1 to 1 correspondence to the airplane's rudder.

Fig. 2 shows the development of yawing moment as a function of rudder position.

Now, further, let us suppose that it is desired to increase the static directional stability without increasing the total vertical tail area. Fundamentally, artificial yawing moment proportional to yaw angle is desired, and this may be obtained by moving the rudder in proportion to yaw angle.

Thus, Fig. 3 illustrates how the rudder may be moved by servo-control proportional to yaw angle to increase static directional stability. Relatively small rudder displacements may easily double the directional stability.

To retain rudder for normal control use by the manual pilot, a split rudder arrangement as shown in Fig. 4 might be adopted. This is equivalent to having two pilots in the aircraft—one who operates a portion of the rudder to improve the yawing stability and the other who flies the aircraft in conventional fashion. The latter, if unaware of the former, would only sense that the directional stability had been improved.

In most practical installations, one rudder surface is used for both functions, the artificial stability and control functions being superimposed by a mechanical differential or by positioning the rudder to the sum of two signals when full servo-boost is available. Normal rudder sizes present little limitation to the use of the control for the two functions.

From the above, it is possible to generalize: (1) that artificial stability is, from an operating standpoint, different from automatic control; (2) that the amount of artificial stability may be varied through changes in sensitivity; (3) that moments proportional to motion variables, such as p, r, q, etc., may be generated, and hence effective changes in the aerodynamic moment derivatives may be produced; (4) that other derivatives not normally available to the designer may be created artificially, such as rolling and yawing moments proportional to angular accelerations; (5) that phase shifts between the variables sensed and the application of control give rise to effects not normally inherent in the basic aerodynamic aircraft, but which through clever design may prove useful rather than detrimental; and (6) that nonlinear effective derivatives or other nonlinear effects may be introduced.

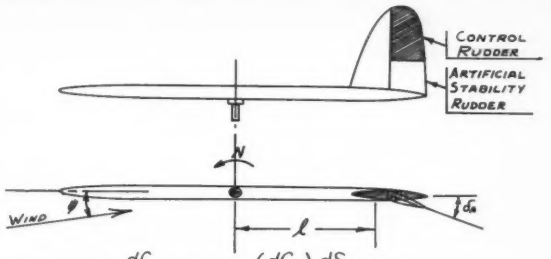
In what situations does artificial stability offer advantages over complete automatic control? Its primary advantage lies in the tactical flexibility it offers by virtue of its independence of fixed ground or external installations or equipment.

In particular: (1) It currently offers a means of vastly increasing the damping of the airplane's oscillatory modes or actually eliminating them. This may result, for example, in aircraft that can perform blind, rough-weather operation more easily and perform actual blind landings with minimum ground equipment.

(2) It offers a partially proved means of gust alleviation or ride control.

(3) It makes available to the designer of modern high-performance aircraft (which must operate over wide ranges of Mach Number, altitude, etc.) a means of "fixing up" the aircraft's stability or creating desirable stability features for given purposes, such as accurate gunfire. In short, it gives to the designer control of the individual stability derivatives of the aircraft in the various portions of the operation range.

(4) It offers variable characteristics for research on special-purpose aircraft and, with artificial "feel" systems, makes available for the first time a truly adequate tool for flying-qualities investigations.



$$N = \frac{dC_L}{d\psi}\psi q S \ell + \left(\frac{dC_L}{d\delta}\right)_A \frac{d\delta_A}{d\psi}\psi q S \ell$$

$$\frac{dN}{d\psi} = \frac{dN}{d\psi} + \Delta\frac{dN}{d\psi}$$

WHERE,

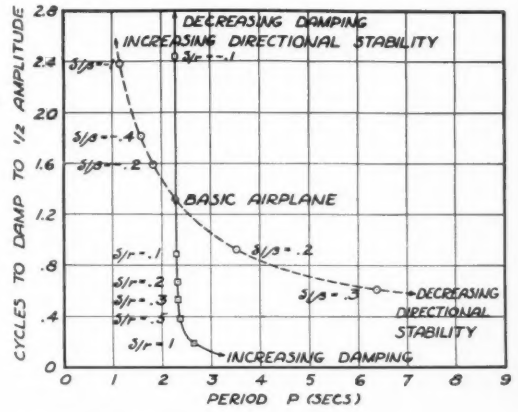
$$\Delta\frac{dN}{d\psi} = \left(\frac{dN}{d\delta_A}\right)\frac{d\delta_A}{d\psi}$$

= ARTIFICIAL CONTRIBUTION TO STATIC DIRECTIONAL STABILITY.

Fig. 4.

In concluding these remarks, several figures illustrating the magnitude of effects introducible by artificial stability are included. In Fig. 5, we have plotted the variation in period and damping of the "Dutch Roll" for an actual case in which artificial stability and damping were available on the yaw axis.

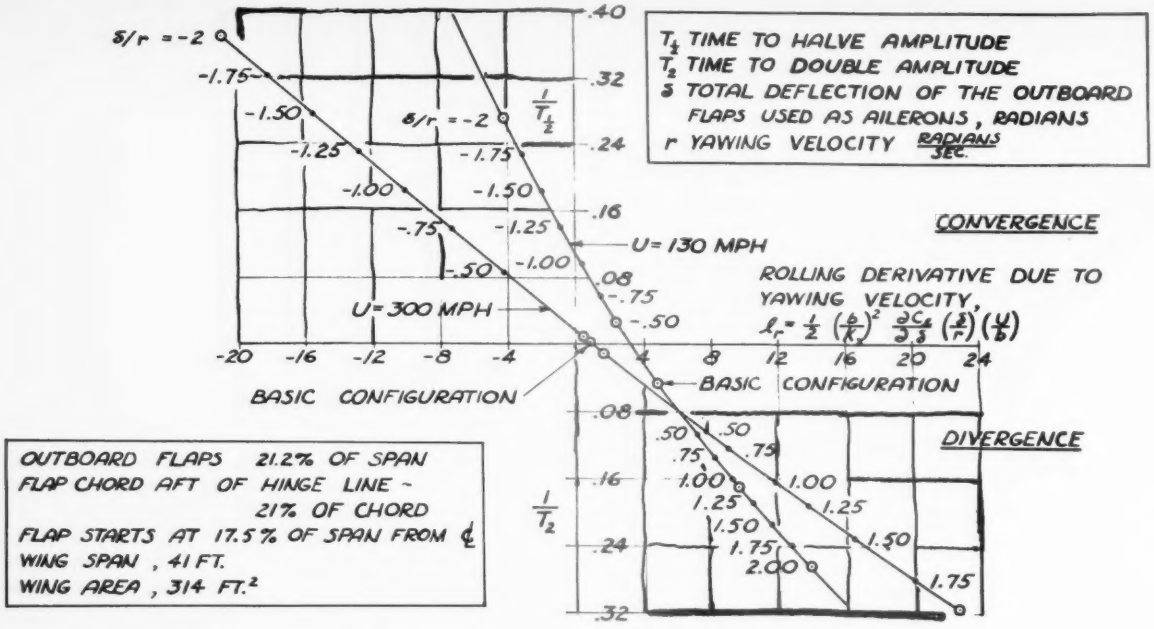
In this case an auxiliary rudder was used. The airplane, a well-known fighter type, had in original form a lateral oscillation of 10–12 per cent critical damping, which is typical of what the pilots have been willing to put up with all these years, though equally typical of the great deficiencies that still exist in conventional aerodynamic aircraft.



δ - AUXILIARY RUDDER DEFLECTION
β - SIDESLIP ANGLE
r - YAW RATE
AUXILIARY RUDDER SIZE 15 % OF TOTAL VERTICAL TAIL SIZE
AUXILIARY RUDDER THROW ± 25°

EFFECT OF ARTIFICIAL DIRECTIONAL STABILITY AND DAMPING ON THE CHARACTERISTICS OF THE LATERAL OSCILLATION
TYPICAL CONVENTIONAL ENGINED FIGHTER
ALTITUDE 30,000 FT.
LIFT COEFFICIENT .2
CALCULATIONS BASED ON "NO LAG" AUTOPILOT ACTUATING AN AUXILIARY RUDDER

Fig. 5.


$T_{\frac{1}{2}}$ TIME TO HALVE AMPLITUDE
T_2 TIME TO DOUBLE AMPLITUDE
δ TOTAL DEFLECTION OF THE OUTBOARD FLAPS USED AS AILERONS, RADIANS
r YAWING VELOCITY RADIANS/SEC.
CONVERGENCE
ROLLING DERIVATIVE DUE TO YAWING VELOCITY, $l_r = \frac{1}{2}\left(\frac{b}{k_x}\right)^2 \frac{\partial C_l}{\partial \frac{\delta}{r}}\left(\frac{\delta}{r}\right)\left(\frac{U}{b}\right)$
U = 130 MPH
U = 300 MPH
BASIC CONFIGURATION
DIVERGENCE
OUTBOARD FLAPS 21.2% OF SPAN
FLAP CHORD AFT OF HINGE LINE - 21% OF CHORD
FLAP STARTS AT 17.5% OF SPAN FROM ℄
WING SPAN, 41 FT.
WING AREA, 314 FT.²

EFFECT ON THE SPIRAL MODE OF ARTIFICIAL MODIFICATION OF THE DERIVATIVE l_r BY MEANS OF AUTOMATIC OPERATION OF THE OUTBOARD FLAPS USED AS AUXILIARY AILERONS

Fig. 6.

APPLICATIONS OF ARTIFICIAL STABILITY AND CONTROL IN DETERMINING THE MINIMUM FLYABLE AND OPTIMUM LONGITUDINAL HANDLING QUALITIES OF MILITARY AIRCRAFT

PURPOSE - Flight evaluation of the minimum acceptable and desired optimum values of significant longitudinal handling qualities of typical bomber and fighter aircraft.

METHOD - Artificial stability and control has been provided in a B-26 and F-94 airplane, capable of varying the eight basic longitudinal stability characteristics over wide ranges.

Basic Longitudinal Flying Qualities	Derivative Varied
1. PERIOD OF THE PHUGOID MODE OF OSCILLATION	C_{m_u}
2. DAMPING OF THE PHUGOID MODE OF OSCILLATION	$C_{m_{\dot{\alpha}u}}$
3. PERIOD OF THE SHORT PERIOD MODE OF OSCILLATION	C_{m_α}
4. DAMPING OF THE SHORT PERIOD MODE OF OSCILLATION	$C_{m_{\dot{\alpha}\alpha}}$
5. CONTROL DEFLECTION PER g OF ACCELERATION.	$C_{m_{\delta_{STICK}}}$
6. CONTROL FORCE PER g OF ACCELERATION.	$C_{h_{\delta\ STICK}}$
7. CONTROL DEFLECTION TO TRIM VS. SPEED FOR 1g FLIGHT	C_{h_α}
8. CONTROL FORCE TO TRIM VS. SPEED FOR 1g FLIGHT	$C_{m_{\delta_s}}, C_{h_{\delta_s}}, C_{h_\alpha}$

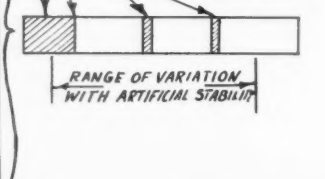


Fig. 7.

APPLICATION OF ARTIFICIAL STABILITY AND CONTROL IN STABILIZING A C-45 AIRPLANE

PURPOSE - To incorporate such artificial stability into a C-45 airplane as to make all its natural modes essentially non--oscillatory and convergent. The aircraft will be employed in the evaluation of all weather flying techniques with varying amounts of dynamic stability.

METHOD - As per theoretical study, artificial derivatives, and a variation of certain of the existing derivatives are provided to obtain the desired dynamic stability without adversely affecting the static flying qualities of the airplane.

ARTIFICIAL STABILITY AND CONTROL PROVIDED

	Effect on Flying Qualities	* Derivative Varied	Possible Range @ 150 mph
1.	Damping of the phugoid mode of oscillation	$C_{m_{ou}}$	Unstable to 100% critically damped - normally 8%.
2.	Elevator control force per g of acceleration	$C_{h_{\alpha_{stick}}}$	5 lb/g to ∞ lb/g - normally 35 lb/g.
3.	Elevator control column deflection per g of acceleration	$C_{m_{\delta_{stick}}}$	8 deg/g to ∞ deg/g - normally 8 deg/g.
4.	Increasing the spiral stability	C_{l_r}	Unstable to $T_{\frac{1}{2}}$ = 4.9 sec.-normally $T_{\frac{1}{2}}$ = 74.5 sec.
5.	Damping of the Dutch roll mode of oscillation	C_{n_r}	Unstable to 100% critically damped. - Normally 12%
6.	" " " "	$C_{n_{\dot{\beta}}}$	
7.	" " " "	$C_{n_{\dot{\beta}\beta}}$	
8.	Turn coordination	C_{n_β}	C_{n_β} = -.5 to +5 Normally C_{n_β} = .14
9.	Increasing the roll stability	$C_{l_{\dot{\beta}}}$	Unstable to $T_{\frac{1}{2}}$ = .05 sec.-Normally $T_{\frac{1}{2}}$ = .15 sec.
10.	Aileron control force per rolling velocity	$C_{h_{\dot{\delta}_{wheel}}}$	.5 lb/deg/sec to ∞ lb/deg/sec.-Normally .7 lb/deg/sec.
11.	Aileron control wheel deflection per rolling velocity.	$C_{l_{\dot{\delta}_{wheel}}}$	1.2 deg/deg/sec to ∞ deg/deg/sec-Normally 1.2 deg/deg/sec.
12.	Rudder control force per degree of sideslip	$C_{h_{r_{\delta_{pedal}}}}$	5 lb/deg to ∞ lb/deg-Normally 11 lb/deg.
13.	Rudder control pedal deflection per degree of sideslip	$C_{n_{\delta_{pedal}}}$	.5 deg/deg.to ∞ deg/deg-Normally .5 deg/deg.

* With minor circuit changes it is also possible to vary C_{l_β}, C_{n_p}, and C_{l_p}

Fig. 8.

Through artificial stability, great improvements in pilot opinion were obtained when the damping was increased to even 20 per cent critical. It is possible to increase the damping to 50 or 60 per cent, which may well prove optimum, for reasonably rapid initial return toward equilibrium. This may also be accomplished aerodynamically if a vertical tail of approximately one-half the wing area is acceptable.

In Fig. 6, artificial stability in the form of rolling moment due to yawing velocity was introduced to modify the spiral stability characteristics. The outboard section of the flaps was used to supply the relatively small amounts of moment required.

Essentially, any degree of spiral stability or instability can be had with this device. Flight experience with this arrangement proved conclusively that our present spiral stability requirement is incorrect by an order of magnitude and that we should require approximately one-half the rate of divergence that we now deem satisfactory. Tests under all-weather conditions would undoubtedly suggest even more stringent requirements.

Finally, Figs. 7 and 8 summarize two artificial stability and control projects currently under way at Cornell Aeronautical Laboratory. The first of these is being performed for the Air Force Flight Research Laboratory, Wright-Patterson A.F.B., while the second is on contract to the All-Weather Flying Branch, Flight Test Division.

Electronic Aspects

By
C. S. Draper

Automatic control equipment is applied in flight for three purposes: first, to provide pilot relief by carrying out operations that are within normal human capabilities; second, to provide control actions that are effectively beyond human efforts; and third, to replace men in pilotless aircraft.

The conventional autopilot is widely used to assume the manipulation of controls during routine flight in order to reduce demands on the pilot's attention. Accurate and fast-acting devices are essential components of modern power plants to make adjustments that are not possible by manual control. For the same reason, gyroscopically actuated servomechanisms to drive control surfaces are included as components in high-performance aircraft. When guided missiles are designed, it is obvious that flight control must be provided by completely integrated control systems.

Knowledge, techniques, and components are now generally available for the design and production of satisfactory control equipment ranging in complexity from elementary pilot-relief devices to complete systems for the stabilization and accurate flight control of long-range guided missiles. As a general rule, the man-designed systems may be expected to produce specific

outputs for particular inputs that are as good as, or better than, the corresponding responses of pilots. This is particularly true after periods of operation which are long enough for fatigue to become important. On the other hand, properly trained human beings are superior to automatic systems in making decisions in situations that require judgment and thinking ability. Optimum results are produced when this decision-making capability is used for monitoring control systems. When arrangements of this kind are used, the automatic features relieve human nerves and bodies of tiring and often boring detailed operations, so that thinking and judgment may be most effectively used in meeting special circumstances and possible emergencies.

Man-made computers designed during the last few years have produced systems capable of giving solutions for complex problems that involve many inputs. For example, computers that now exist will give accurate answers to the three-dimensional problems in geometry and dynamics that must be solved before guns or guided missiles can be effective. When human beings attempt to meet the same situations in the short times available, judgment rather than computation must be used. Computing systems, on the other hand, can give good answers to the special problems they are designed to solve and are well adapted to human monitoring. These combinations of present-day machines and men are able to achieve system performance that is beyond the capabilities of even the recent past. The use of air-borne automatic control equipment, coupled with electromagnetic radiation for transfer of information, makes it possible to leave bulky, complex, and expensive components on the ground under human supervision. This means, in effect, that the same complex of computers and human brains may be used to control simultaneously not one but many guided missiles or aircraft at considerable distances from the control center.

Many people view the striking developments of computers with some fear that man will suffer the fate of Frankenstein and end up as the slave of his own creations. Science fiction is currently devoting much space to this theme and often paints black pictures for the future of the human race. However, it is reasonable to expect that the power of living brains to preserve mastery over their own devices will protect men from this terrible fate.

Control systems, including the necessary computers, are designed because of increasingly difficult performance requirements in terms of problem complications, rapid action, and accuracy. Up to more or less sharply defined limits, desired results are possible by providing carefully trained men to work as teams with control and computing equipment. Beyond these limits, completely automatic systems are required and come into being only at the cost of increasing physical complexity. Complexity, in turn, tends to breed unreliability in operation. The human being is himself more complex than any mechanism he has built or conceived. Men have acceptable reliability in any difficult job only after extensive training and careful selection. Even this expensive procedure is effective only if the men involved maintain proficiency by constant practice. This practice is not needed by properly designed and constructed control systems. On the other hand, physical systems must have constant inspection and operational checks with immediate replacement of substandard components if they are to perform properly. These required services can be provided only by carefully organized and trained groups of human beings supplied with proper test equipment and replacement parts. At present there is a widespread tendency to place full responsibility for operational failures on physical equipment, even though the actual fault may lie to a considerable extent with groups of human beings who are charged with maintenance and operation.

Great complexity does not necessarily carry with it a corresponding degree of unreliability. Present-day telephone systems demonstrate the truth of this statement. In these systems, a large number of wires, coils, contacts, vacuum tubes, and other devices must work satisfactorily on every call. Leaving out of consideration the special circumstances that accompany catastrophic events like fires and floods, telephone-system reliability is generally high because of excellent design, manufacture, and maintenance. When any one of these three factors deteriorates below a reasonable level, unsatisfactory performance will certainly occur.

Electronic devices, particularly vacuum tubes, are regarded in many quarters as especially troublesome sources of unreliability. This opinion is particularly widespread among operators of flying equipment and engineers working outside the control and computer fields. These unfavorable feelings are based partly on natural and healthy reactions to things not clearly understood and partly on bad reliability records of equipment placed in production without a sufficient period of preliminary operational experience. Improper maintenance by service organizations not backed up by satisfactory test equipment and replacement part supplies also often helps to give control equipment a bad name. It is certain that refinements of design, coupled with improvements in inspection, maintenance, and training procedures, will greatly improve the effective reliability of electronic components and the systems in which they are used. When reasonable engineering factors are applied, vacuum tubes and other electronic devices may be designed into systems so that they normally operate with safety margins much greater than those that are possible in modern aircraft structures and power plants. This fact augurs well for the future universal acceptance of control equipment when the current concern over reliability has been forgotten.

Aircraft Design Aspects

By
Harry J. Goett

I would like to pick up where Mr. Milliken left off on artificial stability and discuss its possible uses and

suggest rules of procedure in its use which will enable us to exploit it fully.

First, it is important to note that, although there is a difference in the end results of "artificial stability" (as Mr. Milliken has called it) and "automatic control and stabilization" as we conventionally know it, both actually use the same hardware; if an airplane is equipped for automatic control and stabilization to accomplish some of the purposes that the operational people have already asked for, it will have the hardware necessary for artificial stability. The only difference is the sensing signal that is put into the servo-apparatus. In the case of automatic stabilization, this signal is air speed, engine r.p.m., altitude, or distance off an ILS beam. In the case of artificial stability, it happens to be angle of attack, angle of sideslip, or some such variable to which the longitudinal, directional, or lateral stability is directly related. Thus, if we want to exploit the use of artificial stability, it can be done at little cost in weight or added complication. As a matter of fact, it probably will end up as a considerable weightsaving device when it is used to substitute for a given amount of vertical tail area or horizontal tail area, which must be built into the airplane if the stability is to be obtained by purely aerodynamic means.

Current practice does not generally take advantage of the above-mentioned possibilities of artificial stability. With a few exceptions, it is customary to design the sizes of the stabilizing surfaces so that the airplane will meet the current flying-qualities requirements without any supplementary aid. Then, since the automatic stabilization apparatus is there, it may be used to make the airplane somewhat better from the stability or flying-qualities standpoint. So the electronics is sort of a junior partner at the present time. It is used merely to supplement the aerodynamics.

Actually, I think we have to look forward to a transition period, and at the end of this period it is predictable that artificial stability is going to become an equal partner to aerodynamics in furnishing the necessary stability for the airplane. For example, it will substitute in part for a significant percentage of the horizontal or vertical tail area. When this time comes, the operation of the artificial stability apparatus would be as essential to the continued safe flight of the airplane as the engine is now. An important question is: Just how should we proceed to this point? Should we fight a rear-guard action against it and try to keep the electronics out and consider it a sign of engineering failure if we have to resort to this device, or should we try to set down a method of procedure by which the transition can be made safely and full advantage can be taken of the possibilities of artificial stability?

We have only to look at what has happened in the power-boost field in the last 5 or 6 years to observe how a similar type of transition is being made. Five years ago the absolute demand was that if you had a power-boost system for operating the controls there should always be the possibility of manual reversion in the event of failure of the hydraulic system. In the course

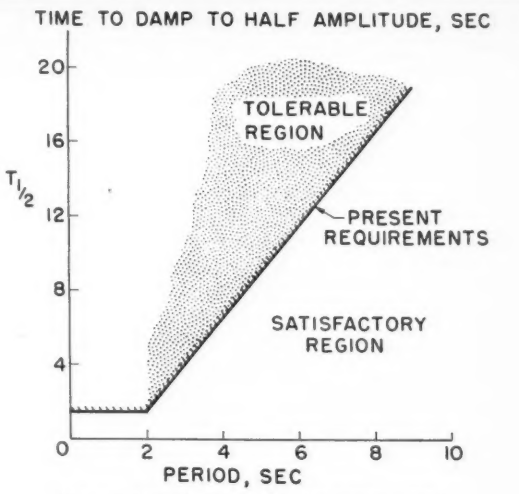


Fig. 1. Lateral period-damping requirements.

of 5 years there has been a sufficient change so that now some airplanes are flying in which, if the power-boost system fails, the failure is just as serious as loss of the engines. Of course, this situation has only been made tolerable by the provision of duplicate or triplicate systems and considerable attention to "fail-safe" systems. I believe this same type of transition should be encouraged with regard to the use of artificial stability and that, in the first part of this transition phase, the airplane should be designed to meet existing flying-qualities requirements with the artificial-stability apparatus operating and that, in the event of failure, it merely be required that the airplane is barely flyable. Flight with the artificial stability apparatus inoperative should be considered strictly an emergency condition, and minimum compromise should be made in the airplane design to meet this condition.

Somewhat in anticipation of the above trend, the N.A.C.A. has been conducting some flight tests in an attempt to set up some guide lines that will indicate just how bad an airplane can get and still be flyable. These flights have been made at Ames Aeronautical Laboratory during the past 5 years in an airplane in which the lateral and directional stability can be varied over a wide range. This airplane is described in some detail in *N.A.C.A. T.R. No. 948*. We took this airplane and had some 20 or 25 pilots, not only from the N.A.C.A. but also from the services and the industry, fly it with a wide range of stability settings. One typical result of these flights is shown on Fig. 1, which is taken from data published in *N.A.C.A. T.N. No. 1936*. The present flying-qualities requirements call for an airplane to have lateral-directional damping such that it will fall in the region below the solid line on the figure. We have flown our airplane in this region and invariably get the answer: "Yes, if you put the airplane in this region, most everybody will think it is satisfactory." However, we have also flown it up in the shaded region, which is labeled "tolerable," and the pilots generally come back and say: "I don't particularly like this but

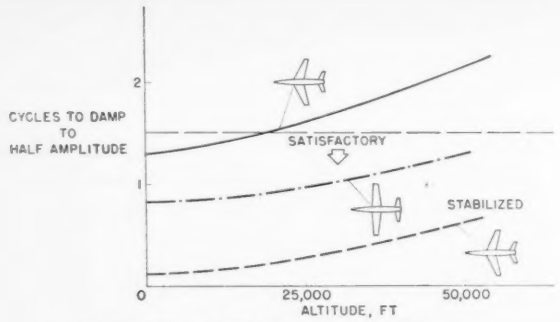


Fig. 2. Effect of altitude on directional damping.

in emergency conditions I can continue to fly the airplane. It takes more concentration and I would not want to do it too long, but I can fly it." Beyond the boundaries of this shaded region, we have actually found conditions in which the pilots have considered the characteristics intolerable. The definition of these boundaries should not be interpreted too strictly. There are actually places beyond it which we have not been able to explore because of the limitations of our apparatus. However, on other parts of the chart where we have gone beyond the shaded region, the pilot comes back and says: "If this thing happened to me in a normal flight, I would have serious difficulty handling it."

What I am proposing is that aircraft design practice should be to design the airplane to fall in the "satisfactory" region with the automatic stabilization apparatus operating but that, at least for the present, if the automatic stabilization apparatus fails, it will be permissible for the characteristics to deteriorate to the extent that the airplane falls in the "tolerable" region. Gradually, as our confidence in the reliability of the automatic stabilization apparatus increases, this last stipulation would be relaxed, and eventually the continued operation of the apparatus would be a necessity for continued flight.

The possible benefits that would be gained if we followed this recommended course is demonstrated in Fig. 2. This figure shows the effect of increased altitude of operation on the directional damping. The "satisfactory" boundary is essentially that shown on Fig. 1, although it is expressed in a different manner. As the altitude increases, the damping decreases, and when we design airplanes to operate at 40,000 instead of 20,000 ft., as is the current trend, the requirements of tail size are going to be considerably greater. Furthermore, on a swept-wing design we start out a lot worse off, and soon, if you use normal ratios of tail area to wing area, the airplane will be up in the unsatisfactory region. The bottom line on Fig. 2 shows this same airplane with a readily achievable amount of artificial stability fed into it. Such an airplane would have a considerably smaller vertical tail than one that attempted to achieve the same purpose by purely aerodynamic means, and this would show up, I believe, in a considerable weight-saving.

The same application can be made with regard to the longitudinal stability. For example, we have made some computations with regard to a typical transport airplane and have assumed that the automatic stability apparatus is arranged so that it will move the elevator 1 deg. for each degree change in angle of attack. This would provide an added amount of longitudinal stability sufficient to shift the neutral point back 15 per cent M.A.C. This could be used either to increase the range of permissible loading conditions of the airplane or to substitute for a given amount of tail area.

In summary, I am suggesting a change in our design approach from the present, in which automatic stabilization apparatus is used as a purely supplementary device, to a point where it is used as an absolute essential to the flight of the airplane and as a substitute for a significant amount of the stability now supplied by the airplane aerodynamics. This obviously will require considerable improvement in the reliability of the automatic stabilization apparatus, and an expedient such as duplication or triplication which is now resorted to in the power-boost field presumably must also be applied to the automatic stabilization apparatus. Furthermore, to exploit fully the possibilities of artificial stability, its use will have to be integrated in the initial design rather than resorted to somewhat as an afterthought, as is presently the case.

Electronic Aspects

By
Paul R. Adams

We have been asked to consider first what can be done right now. I think this is one of the reasons why most of the people have so far talked about just stabilization—getting artificial stability—rather than about the more ambitious phases of servo-control. Nevertheless, I wish to speak about fully automatic control and especially about automatic landing.

I have been primarily interested for a long time in ILS automatic landing—that is, actual automatic touchdown. It has taken me considerable time to decide we weren't yet able to do it with enough reliability to justify commercial adoption of zero zero minimums. You understand we have made many fully automatic landings. So have many other companies. It is only after you have done a lot of it that you realize it is not yet safe enough to depend on under bad conditions.

However, I am convinced that the servo is here to stay. It is perfectly logical to say that it shouldn't be used until it is perfectly reliable and perfectly accurate and perfectly safe. But the world is not logical. The world didn't wait until the airplane was perfectly reliable and perfectly safe. They just started flying, and then airplanes had to be made better or else.

In the same way men are now beginning to make more and more use of servos, perfect or imperfect. Therefore, it is up to us to make these safe; because, ready or not, I predict we are going to use servos. The growth of this tendency is not only in aeronautics but

everywhere. Servos have been doing many jobs very well, jobs that *no man and no other machine* can do, and now we cannot get along without them.

One of the things that we electronic engineers have been interested in is to make the automatic landing do what we know it ultimately will do—be *better* than the human landing. So far, it is very far from that. An automatic pilot properly coupled to the ILS receivers can land in good weather (with another pilot watching) on a runway that is rather wide and long. But a human pilot would be terribly bad if he couldn't do that before he first soloed.

A good automatic landing should touch you down and stop you on a runway only 10 ft. wider than the span of the two main wheels and in a stopping distance no longer than the distance required for braking plus 200 or 300 ft. (to take care of gusts); then you should be able to do much better.

Obviously, the job of landing a large fast bomber on a carrier for the Navy is a difficult job for a human pilot. They are trying to make larger carriers to carry larger airplanes, but one of the possible alternative solutions to the problem would be to use automatic control to make an airplane land in a much more limited spot. An airplane can be catapulted from a standing start to full flying speed in a few scores of feet. There is no reason why we coudn't fly back down a catapult if we really knew what we were doing.

Seriously, I think, in my lifetime, we are going to see automatic controls practically flying an airplane back down a catapult and stopping a large bomber on a carrier so small that you can't put the bomber below deck. We are not limited by the physical size of the ship. The carrier will not sink under the bomber. The reason why we can't do that now is simply that we don't know accurately what we are doing. It is simply that the *control* job is being poorly done.

We haven't begun to scratch the surface of what can be done with automatic control of flying. New techniques are coming forward which may soon increase the speed and accuracy of flight control by an order of magnitude or more. Some of the techniques discussed by General Kelsey, such as measuring the relative air motions by yaw vanes and angle-of-attack indicators, are beginning to be accepted in automatic flying, although they are still fairly new. Also, some of the devices referred to in Mr. Draper's discussion are generally accepted, though fairly new.

I want to call your attention, particularly, to one of the factors which is accelerating this revolution in control engineering, this constantly increasing utilization of the servo—aside from the obvious fact that we are now making the servo components much better. Why are we using servos for so many more complicated jobs and so successfully?

One reason is that we have stopped trying to figure out what we are doing and are letting machines do this figuring for us. We have stopped trying to solve the more complex equations by hand on a piece of paper and are, more and more, using analog computers in the design stage.

These are not the marvelous and enormous digital computers so widely publicized as almost like a human brain. I claim that they aren't even really computers at all. They are more nearly simulators that permit solving the complex computer problems by a sort of cut-and-try process, using adjustable circuits or servos to represent the winds and the airplane motions and the control surfaces, etc.

The problems they solve by cut-and-try can be written down as differential equations by ignoring a few limiting conditions, but they are often messy equations—say of the seventh order. A mathematician could probably solve such an equation fairly well by reducing the seventh-order differential equation to a seventh-power algebraic equation and then having it figured out by a sort of arithmetical cut-and-try method by a corps of girls. But he wouldn't have enough time to make enough tries to find out what was the really *best* way to solve the problem because he would be so busy solving the equation that he had set up to represent the problem.

The analog computer or simulator, which almost every aerodynamicist and servo designer lives with now, is doing the job of mathematical thinking for us and doing it much better, because of the fact that it handles the problems or equations very fast and because it will take care of limits and boundary conditions that don't fit into the pencil and paper method. Many of the engineers who are newly growing up in this field are learning to think of a certain simulator setup as directly representing their real physical problem; they don't think of the computer as solving mathematical equations that, in turn, represent the physical problem. For them it is primarily a simulator.

Others who have had a lot of experience in representing physical servo-problems in operational notation think it easier to learn to translate that notation into integrater hook-ups and feedback loops than to think directly in the latter form. For them, therefore, the machine is a computer.

In either case it is now recognized that the analog simulator (or computer) is a respectable way of doing it. It doesn't mean that you aren't educated. Just as it has been found that for sheer accuracy a machine can fly a plane better than a pilot, so also we engineers are beginning to recognize that it is perfectly respectable to have a machine for part of our engineering.

I want to point out one other thing. There are two machines—two types of computers in general use—the high-speed electronic type and the "real-time scale" electromechanical type. The "real-time" machine is high in cost, and in some quarters there is an impression that it is the best machine to use for all work.

The fast-time machine is, now at least, as widely used; yet some people still consider it inferior because it is available for a low price. Actually, I consider that the fast-time type is better than the "real-time" machine for most initial design work.

You may think you don't care if a machine goes through its formula within 1 min. or within 1/60th or 1/1,000th sec. But if it is fast enough so that you see it as you would see a moving picture, you can see trends and the influence of the parameters, and you can get approximately where you want to in a few hours or, at most, a few days.

If you do it the other way, the machine is just slow enough so you can't rely on memory but instead must make a record of it. Then you have a bookkeeping job, and that is slow. The way you use these slower machines is that you run off a recording with certain settings and you make a record of all the conditions of the setup and an index of it. Then later you forget what happened, and you have to look back and take out three recordings and compare them. With the fast machine you forget, but you try all over again. If you have a fast machine, you can find out all over again quicker than you can look up the records.

The fact is that both machines have their uses. The fast-time type is in my opinion much better for preliminary design. The "real-time" machine, however, is generally conceded to be the best one to be used in the later stages.

In addition, the "real-time" machine has the great advantage that it can be used for actual testing of components of the system under simulated flight conditions.

The relative advantages of the two types of machines were well illustrated by some work done last year jointly by our Mr. Alexander and the Air Force's Pat Kelly, who was killed recently in the crash of the All-Weather Experimental Airplane. Just before he was killed, he was working with our company. He had a "real-time" machine, and we had one of the other type.

We were working out some problems on automatic landing in windy conditions. One of the things that we discovered all over again (although I know that at least several others discovered it earlier than we did) was the fact that when you are trying to fly on an automatic landing course you should *not* try to keep the plane flying straight.

You take an ordinary automatic pilot, and when the airplane turns from its heading, it immediately acts to get it back to its previous heading. Actually, the first thing you should do is just disconnect that heading control, because, when the wind hits the plane from the left and blows its tail around so as to head it to the left, you ought to let the plane weathercock into the wind. You can make the errors about eight to ten times less if you leave the airplane free in heading.

Well, we guessed that this might be true, and within a few hours we had tried it on the fast machine and found it was true. Then Pat Kelly tried it on their "real-time" machine, and it was proved definitely true that the heading control should be taken out when you are trying to fly the airplane along a particular course.

This, of course, led us to carrying the principle still further. We said: "Suppose we had a yaw vane and used it to increase the weathercock effort," and we tried that on the simulator and proved that this could make it still better.

These experiments were all performed on the fast simulator first and later checked on the "real-time" one. The new methods weren't tried out in actual flight in any of these experiments (but were later confirmed by flights made by others).

When we tried working with this machine, we soon became convinced that this was a remarkable new tool. We weren't the first to learn this, of course, and we won't be the last. I just wanted to call it to your attention, because perhaps 20 per cent of you aren't using those machines, and I figure that, if you don't use a servo-machine where you can, you are old-fashioned.

Aircraft Design Aspects

By

A. L. Klein

I am an airplane designer, and I am against almost everybody so far.

First, with regard to General Kelsey, I would like to point out that one of the first weapon systems developed was used by primitive man; in this system the weapon returned to the hand of the user if it didn't hit anything, and it had no gadgets of any sort. This boomerang was a programmed automatic flight device. I don't think our mathematicians have caught up with it yet.

When some of our people talk about setting up equations of motion and putting them in analogs and coming out with what they should do, we think they should start in with the first device, the boomerang, and solve that first, and maybe they can take something that has more degrees of freedom in the device itself.

In this business there is a radical and sharp division of fields of interest. I happen to be in both of them—the commercial and the military fields. What goes in one, doesn't go in the other. It is well for all of us to keep remembering all the time that we have airplanes making hundreds of landings a day at commercial airports, and something like 99 per cent reliability would result in each major newspapers having a chance to put in headlines: "Crash at the Airport Today." That is, our own airport, because we would have more than one a day if we only had 99 per cent reliability. We have to have at least an improvement of two orders of magnitude or even better than that, maybe three, to tolerate automatic systems for commercial aviation.

I don't know what the number of daily flights is. I know there are some 75 a day scheduled between New York and Boston. This is just one intercity operation. So just remember that you would have to have an extraordinarily high degree of reliability in order to tolerate automatic devices in a density of operation where you are endangering the lives of a number of people.

The airplane designer's task is to make an airplane that is a safe device and an economic device. These two demands are not separate from each other. The cost of a major air-line accident, as an example, is

extraordinarily high—not less than $12,000,000 and maybe closer to $25,000,000.

To say that you can afford an accident is nonsense. You can't afford it, even for financial reasons, no matter what we feel about the other things. One accident is too many accidents. Therefore, we must always be sure of our reliability.

Mr. Draper said something about automatic telephones. I lived in Los Angeles as a boy. We put in the first city dial telephone system, and I can tell Mr. Draper that it didn't work, because you could dial various numbers and only one time out of three did you get a number. Now, after 50 years of development in this field, we still have a lot of trouble. In fact, when the Bell System put in their Mark 4-cross bar telephone system here, the cross-bar exchange, much to their astonishment, became manic-depressive, and under certain circumstances it would close all the switches and just stop. We have these examples before us in allied fields of automaticity to remember.

Somebody said something about reliability of aircraft. A year or so ago I made an analysis. It was crude. I made an analysis of the C.A.A. Daily Trouble Reports, and I found that 50 per cent of the reports showed engine troubles; 25 per cent, approximately, were gadgets; 24 per cent of them, approximately, were things that wiggled on the airplane—doors, control service devices, landing-gear doors, and the rest of these mechanisms. Only 1 per cent of the reports showed aircraft structure trouble.

There is a good old motto for the airplane designer: "If you don't want to have trouble, bolt it up tight and don't let it move."

I understand that Mr. Ciscel is in favor of power boosts. I was a codesigner of a Douglas power-boost system about 19 years ago. We used it for about 1 year, then we took it off the airplane. We found it flew better without it.

The reason we don't like to use power boosts is the following: They are a mechanism. It is a piece of automatic mechanism, with all the features of an automatic mechanism. It is an amplifier. It can howl, scream, etc.

An airplane has an extraordinary number of degrees of freedom. It isn't rigid. It has freedom of motion and control—at least nine simple degrees exist. It has deflection modes, such as antisymmetrical, torsional, elevator modes, and things like that. When you get through counting up these things, it takes at least 24 variables to represent the simplest modes of oscillation of an airplane. If the natural frequency of one of these boost devices happens to synchronize with any one of these, then you may be in real trouble and have pieces flying off the airplane.

It isn't one mode you are adding. You are adding at least 20—maybe 100—every time you put in a power boost or an oscillator, and you increase the possible modes of operation of your gross device enormously. We now handle 20th- to 30th-order matrices in order to run these things down, and yet we can't foresee all of them.

We feel that the fewer degrees of freedom that you have to your gadget, the better off you are. We have a better chance of taking care of the ones we have. But the more you put in, the more troubles you are likely to have.

In addition, the mechanism itself is subject to certain troubles. About 5 years ago, at an I.A.S. meeting, I had an argument with a group of pilots concerning the control forces, and I expressed a personal opinion that pilots are much too lazy. By law, they work only 6 hours a day. They get very high pay and all sorts of protection. A guy down here on the street, driving an intercity bus, with about the same number of people behind him, works 8 to 10 hours a day and receives perhaps a tenth of a pilot's pay. He has to work.

I don't know why we should make these controls so delicate. They are so delicate that, if somebody in the cockpit falls against them, there is great danger that the wings of the plane will come off.

So far as automaticity is concerned, there are two kinds. They are what I might call "wrong base" automaticity. Most of us have had trouble with automatic cowl-flap controls, in which an engine has a certain temperature, and you figure out what it is going to be 5 min. later, and you run a motor or something that will move the cowl flaps to the right position.

We have one of these on a current production airplane that doesn't work at all. It has gone through innumerable tests, and it doesn't work. We are forced to do this by the user.

We have another airplane—the A-26—that doesn't have any device on it whatsoever, but it has automatic cooling. That particular airplane happens to be a success because the cowl flaps are in such position that, when you open the throttle, additional exhaust-gas jet action serves as a pump, which increases the airflow through the cowl flaps, and the cowl flaps only have to be set for outside air temperature. You can run the power up and down, and the engine cools all the time.

In this case, the amount of cooling the engine gets is based directly on what is happening in the cylinder, and you are using that effect to produce the correction. This was an accident, of course. We were not smart enough to build things this way.

As far as complexities go, there are two kinds: (a) parallel complexity, as represented by a manual telephone exchange. In this kind of complexity, if something goes out, you just don't use that thing. It doesn't affect the system at all. (b) The other sort of thing is sequential complexity, where you have a long chain and, if any link in the chain goes bad, you are in trouble.

This nine-horse parlay is the sort of deal that you have in an ILS coupled-autopilot landing system. You are presupposing that system is working properly and that the ground is dry, or wet, and that it is set properly. You are assuming that the receivers on the airplane are functioning properly and the coupler is operat-

ing properly, and you assume that the airplane is balanced with its c.g. within its proper range. If all of these things are right, the system is safe. But with this sort of system, there are many chances of error.

As far as the future is concerned, the key to the future is simplicity. If we can only get back to the prototype of our weapon system—the boomerang—we are "in." This makes it a machine-shop job, and once it is that way, there isn't anything wrong or anything to adjust.

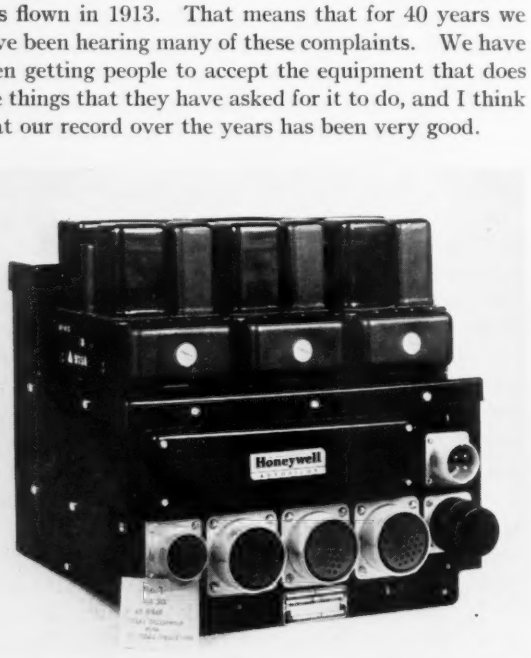
The other thing that we have to do on these things is to analyze the possibilities of failure, and those of us who have been in the missile business know how hard it is to analyze or to anticipate all possible failures. A typical missile development group has fired a missile, and they look at their telemeter records and try to figure out—"What the hell!" With that, I will stop and may say something more later.

Electronic Aspects

By
B. H. Ciscel

The people from the services have spoken their piece and said what they want in the way of performance and reliability. The people from the research groups have spoken their piece and said what they want in the way of performance and reliability. You have heard from the airplane or air-frame manufacturers and what they want in the way of performance and reliability. And now, thoroughly in keeping with tradition, they turn to the equipment manufacturer and say: "How about it?"

Well, the equipment manufacturers have become accustomed to this situation. The first automatic pilot was flown in 1913. That means that for 40 years we have been hearing many of these complaints. We have been getting people to accept the equipment that does the things that they have asked for it to do, and I think that our record over the years has been very good.



Courtesy Minneapolis-Honeywell Regulator Co.
MH-15 and MH-20 helicopter autopilot calibrator and amplifier assembly.

Courtesy Minneapolis-Honeywell Regulator Co.
The control-stick component of the MH-15 helicopter autopilot system.

I haven't any idea how many automatic pilots the Sperry Corporation has made. I know we have made around 40,000. Both Sperry and Eclipse-Pioneer, Bendix, have made a great many. A reasonable estimate might be 100,000 automatic pilots versus a few documented reports of failure of automatic pilots resulting in destruction of aircraft. That means that, in our design of automatic pilots throughout the past, we have done pretty well in, as Mr. Draper says, "fighting for those extra ounces," and yet producing equipment that has reliability built into it.

Before we get into answering the various questions that are going to come up and get to the state of charges and denials, etc., we should define some of the current types of equipment.

The people who are building automatic pilots see them classified in various ways, one of which is called the "relief autopilot." This was the sort that was first flown. This is the equipment that the air-line pilots need, in addition to low control forces, to keep them from becoming tired. It holds the airplane still for them while they are flying, so they can watch other things. The relief autopilot has had a long and useful career in eliminating pilot fatigue. It still is very high in demand.

The "bombing autopilot" became prominent during the past war, when it was proved that the automatic pilot could do more accurate bombing than in the human pilot trying to follow an indicator. That was a great day.

Starting along about 1947 or 1948, we began to get demands for what we called "dynamic dampers," the sort of thing Mr. Milliken talked about in connection with these artificial stabilizers. Over the past 5 years, we have seen an increase in demand for single-axis yaw

dampers up to four-axis dampers to handle all sorts of unstable and complicated aircraft.

We have been faced with the problem of building up what we call "fire-control automatic pilots" for tying into radars and computers. This is an example of a situation where the human pilot reaction time is not fast enough to satisfy the dynamic requirements.

Finally, we have come to what we call the "complete autopilot," and that name is derived from the fact that it has a lot of auxiliary black boxes, for beam following, etc., leading up to the monster-type devices as the "master sequence selector," described previously.

Even though we have this broad range of equipment that we are supplying, we find that we must continually change our sights to meet other demands. For example, the one thing that is missing from this panel is a procurement agent—somebody watching the bankroll of the company involved.

Our equipment must be competitive economically, as well as in function, size, and weight. As a result, we must look carefully at the mechanization of various flight-control systems, so that we don't have so many gadgets that the system is not salable or serviceable.

Yet, we have come up with newer equipment with performance to satisfy the dynamic requirements of the next generation of aircraft, even though we find ourselves continually hemmed in by requirements covering size, weight, temperature, and vibration. We feel we are doing an adequate job, and we look forward to hearing the comments of this symposium that we might have further guidance.

Discussion

Chairman Warner: Others are no doubt struck, as I was, by the enormous emphasis that has been placed on reliability and by the different complexion that the whole problem of automatic control assumes in flight operations when the improvement of reliability has reached a certain stage.

The difference between 10 per cent failure and one-tenth of 1 per cent failure is a difference in degree. The difference of one-tenth of 1 per cent and one-millionth of 1 per cent is something else. When it gets that low, you can act on the assumption that there aren't going to be any failures. You can design aircraft to use automatic control on the assumption that you are always going to have it (just as you assume you are always going to use two engines or more), and you don't design to "fail-safe." You duplicate enough so that you can assume that you will never fail completely.

How near we are to attaining that infinitesimal probability may be further developed in subsequent discussions. . . .

Admiral Hall: I would like to ask Mr. Draper if he has considered the extraordinary difficulties we have met at times in obtaining adequate numbers of components commercially in peacetime, particularly, in competition with television and radio sets, and the problem we might be introducing into our aircraft when it comes to rapid expansion of numbers in times of war?

Perhaps Mr. Ciscel can also give us some ideas on industry's ability to furnish reliable components or adequate devices quickly when we need them.

Mr. Draper: On the matter of getting more reliable systems and components, I feel that you are in the same situation here that you are when you consider the purchase of any aircraft components. You can go down to the corner hardware store and for a few cents buy a 3-in. bolt that is good enough for certain purposes. But if you want it for an airplane, you have the "AN" stamped on it, and you can't buy it for a few cents.

The difference is that you really take seriously the matter of wanting that bolt to be reliable and good. . . . The extra money you have to pay is for increased care in design, in materials, in machining, and, above all, in inspection. . . . The control people can certainly get this greater reliability if they are encouraged and are allowed to design for it.

As to the matter of procurement, it seems to me that one of the things that the control business has suffered from is that the vacuum tubes were common. They were cheap. The people who made vacuum tubes found it was more profitable to make a lot of tubes to some reasonable standards and make them cheap. They could let the customer use them and do the inspecting. If the tube failed they would simply give him another one.

If you are going to accept this mental attitude, you certainly can't expect tubes that will give the kind of reliability we are talking about. On the other hand, if you are willing to use the methods of inspection that are available today (remembering that the vacuum tube is not in itself a large item of expense), I don't see why the components couldn't be made available and reliable. . . .

As to how many you can get, I would have to turn this question over to Mr. Ciscel. . . .

Mr. Ciscel: I would like to add to Mr. Draper's preliminary remarks before saying anything about quantities—the point being that dependability is basic quality, defined. In bandying a lot of numbers like 98 per cent, and failure of one part in a million, and order of magnitude, the presumption is that we can measure these.

Actually we find, as equipment or mathematical equipment manufacturers, that the dependability figure is an evasive operation. It represents summation of design techniques, test procedures, inspection practices, maintenance, quality, and—above all—acceptable performance in service.

It follows that dependability is a measure of the realistic attitudes by supply and procurement groups in the formulation of specifications covering the system. Specification is a horrible word, but it is a good measure of how well we are doing in the manufacture of any equipment. . . . Specifications covering automatic pilots have been growing in terms of details of the equipment.

We started out with requirements for the performance of systems. We are now faced with detailed requirements of each component—knowledge of whether it will stand up under temperature, vibration, etc. That is all involved in the system.

So we wind up with both the system and series of components, each of which has been built, inspected, and tested to rigid specifications, and we say then that we have built what we think is good dependability into the equipment.

Unfortunately, that hasn't proved to be enough. We come to a point where we are faced with a still greater requirement—that of fail-saving or fail-safe.

This fail-safe requirement is nothing new. We have several ways of accomplishing it. As long as we are on this subject, we might go into some of the means that we have come to use to guarantee dependability and safety above and beyond that which is built into the inherent equipment.

This is something, I think, which is of interest to airplane people, because in their structure analysis, etc., they build the equipment to a certain degree of safety. They use "factors of safety." Having gotten there, the point of going beyond is seldom done. But in automatic equipment, we have had to come to what we call monitoring and limiting systems. The most common type is the signal monitor. We look at the signals going into that; if they look flukey (we don't care where they are acting), we can disengage the automatic pilot.

There is also another scheme called the gyro monitoring, where a gyro is affixed to the airplane. To make the automatic pilot practical, the gyro responds in such a way that the airplane also is in close coordination with it. If the airplane and gyro are not responding the same, it is assumed that the automatic equipment isn't working.

Another scheme is that of stress-monitoring. That has difficulties in instrumentation, since different parts of the aircraft are likely to be under critical stress at various modes of the flight, under certain air-speed conditions, etc.

That means that, as you vary your air speed or flight conditions, the part you are worrying about may not be the thing upon which you are measuring the stress. . . .

By far the most common method of building in additional safety to automatic control systems is called "servo-limiting." This is done by limiting the torque . . . the travel. . .or the amount of time that a servo can put in full control. . . .

There are accelerometer systems and others. Without defending or justifying them or picking any one as the best (since this will vary with the application) we do have adequate capabilities of producing the presently known quality and quantities of equipment.

What may be required in the future—particularly if we get into large missile production operations—is a good question. Somebody will have to make some arbitrary decisions as to how far we can go into automatic control equipment.

Chairman Warner: Now I would like to have some questions from the audience.

Mr. Wenner (W.A.D.C.): In view of the future requirements, such as transonic flight, swept-wing configuration, etc., we may be severely limited because of operating performance requirements. How much are you willing to sacrifice in this reliability that everyone mentioned to get your performance requirements?

General Kelsey: I'm all in favor of automatic flight, with the pilot monitoring it. I think the only requirement pertinent to your question is that you shouldn't use any of this automatic equipment to get yourself into a worse position than you would have been without having it. . . .

This is not specifically an answer to the question. But I think, if you translate it into operational terms, what you are saying is that you can only justify the superimposing of these equipments that we are talking about on flight for a complete dependence on them in the pure research field. . . . For dependable operation, your basic design parameter is that you use this additional performance to prove your admission capability, but you don't depend on it to get you extended into a range that you can't get to otherwise.

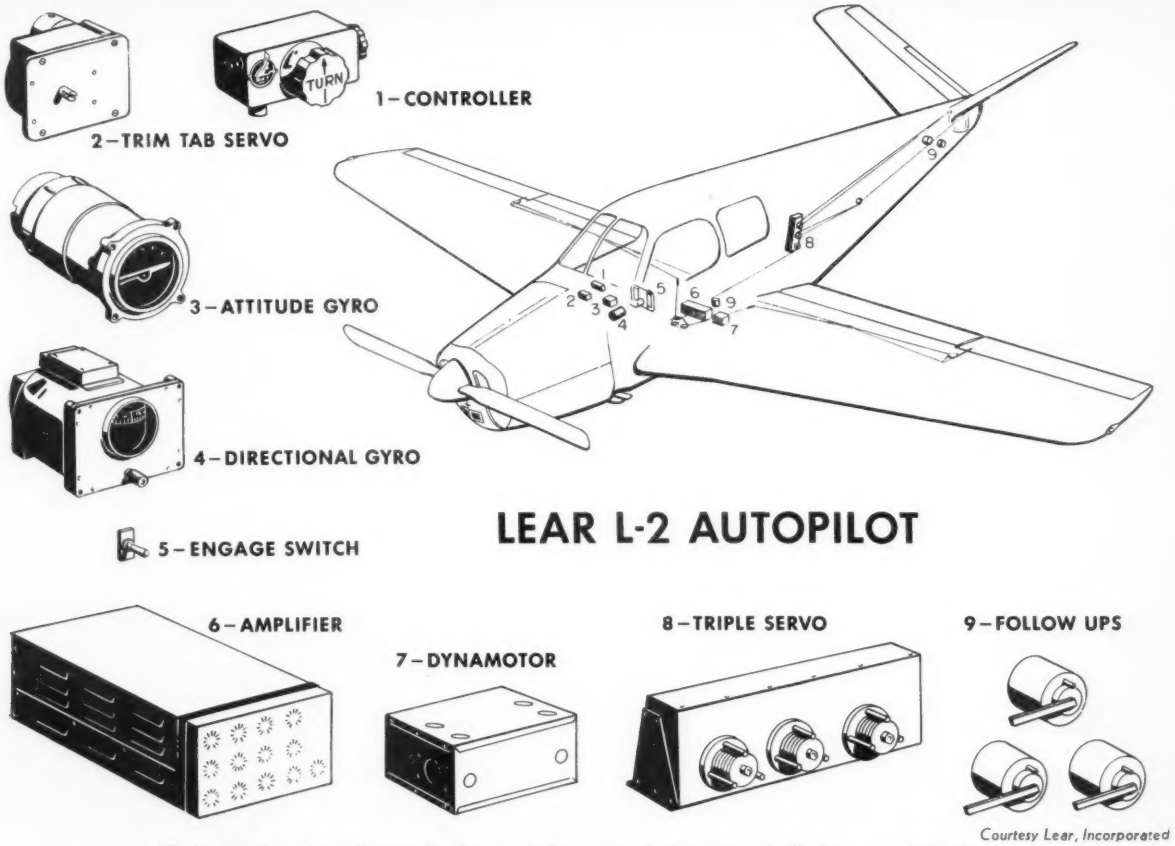
Chairman Warner: Does anyone want to add to that?

Mr. Klein: I think we can say that we don't know how to do a really good job with these types yet. There has been extremely limited experience. I feel that, if we work on them, we will be able to ameliorate the requirements on patch-up gear. So far, there are, I think, eminent improvements in many of the aerodynamic control characteristics and other things. . . .

So this is a special case. It should be distinguished from the military cases. The test aircraft in these fields will probably for a long time to come carry a lot of equipment that is there to help the pilot if he needs it to get through and come out of his difficulties. But this gear should be eliminated, if possible.

Mr. Smith: I would like to hear some discussion on how you would handle these problems in connection with helicopters.

Mr. Ciscel: One of the things that has amazed me just a little bit is the tone of some of the discussions and questions. To go back to General Kelsey's remarks—namely, that we could justify completely automatic control on research equipment—and now Mr. Smith's question about helicopter stabilization, etc., imply that we are discussing something that is not already "after the fact." We have already come to the point in our technology where this equipment is not "breadboard" or "drawing board," as implied.



Courtesy Lear, Incorporated

The Lear L-2 is a typical example of a practical autopilot designed specifically for use on light planes.

In supersonic craft, everything on the drawing board and about to be produced appears to be in need of the sort of artificial stability equipment that Mr. Milliken has discussed. We, of course, are in a position to supply that equipment and are very much concerned over the problems that it involves. On the other hand, as I also indicated, the requirements for adding artificial stability are different in terms of the amount of authority that is required of the automatic control equipment....

Artificial stability derivatives, although possible to obtain through mechanical or manual controls and systems, appear to be more feasible through electronic devices. The helicopter, itself, is difficult to fly and has been made much more acceptable in terms of pilot operation and pilot fatigue by the addition of two innovations—one, the hydraulic boost and, lately, the completely automatic pilot.

So, as I said at the beginning, I am just a little amazed at the tone of the discussion—that we should think that these things are all in the future and should question whether or not we should go to them. They are already here. We have gone to them (and it has been done by people of good engineering judgment) as being the way that appears to be most feasible in accomplishing certain desired end results.

J. C. Hunsaker (M.I.T.): I have an idea that we are approaching a kind of a barrier. Some engineers think that the automatic control devices should be applied in such a way that, if they failed, they would fail-safe. That is an implication that the airplane can still be handled by the human. And if we said that we would not use automatic devices unless the airplane were still flyable, we would stop progress in the art.

Now with the use of electronic and other devices in aircraft and missiles, we are being pushed up into regions where the human pilot, except for his function of judgment, may be quite helpless and certainly helpless if his device has failed.

The only way such devices may be "fail-safe" is that we duplicate the flying machines, leave the pilots at home, and produce more of these devices. So perhaps someone should raise the question: "Has the human pilot any business to be flying at supersonic speeds and up into ultraterrestrial heights?"

Mr. Goett: I have been trying to put myself in the position that Mr. Klein has chosen to take and have tried to figure: "Well, okay, now the operational people have asked us for certain things." But how, if we don't use automatic control, are we going to meet their requests?

To make this question specific, take the request of Mr. Pike, from the standpoint of his cruise control,

Courtesy Gavco Corporation

Designed for rugged use in high-flying aircraft, the new Gavco Exciter Voltage Regulator, Model 13RG-B, incorporates many electronic innovations for quicker response, safer operation, and more stable regulation.

which is a real tough one to me. I'm not even sure that it can be met automatically. Just what automatic or aeromatic means, Mr. Klein, would you propose to meet this close control of speed?

To make the question a little bit broader and cover one of Captain Jensen's questions about all of the instruments he has to watch: "By what means, other than by making some of these operations automatic so that they don't require the pilot to look at them, are you going to accomplish these requests?"

Mr. Klein: Well, of course, I don't know right off the cuff how these requirements should be achieved. One should, of course, make a preliminary investigation of the possible ways of achieving these things. For instance, if improving the longitudinal stability is a desirable thing to do, it is possible to do it by adding a counterbalance weight below the column. It has been done on several airplanes. And this is just a plain weight. It doesn't ordinarily weigh as much as an autopilot and certainly has less maintenance than an autopilot. . . .

This may be one way of doing it. Ordinarily, we try to solve this sort of question by a multiple attack and then make an assessment of the advantages and disadvantages of each method. This is the only way I know of answering such problems.

I would hesitate to say offhand that I could accomplish them by purely aerodynamic means. At the same time, I would hesitate to say it was necessary to use electronic means exclusively. I believe rather firmly that anybody who says, "You must do a thing this way or that way," isn't being an engineer. He is being a salesman.

So you have to remember that you have an objective to achieve, not a method of achieving the objective. The objective itself is the important thing.

Dunston Graham: I would like to ask if it isn't true that the aerodynamic method of controlling speed is drag and that drag is the last thing you want to add? The weight, as I understand it, will decrease the speed.

Mr. Klein: This is possibly true. But everything on an airplane is drag or it is weight. The drag causes increased fuel consumption and, therefore, weight. The weight is something you have to carry around, and therefore it causes drag.

We always (for any type of airplane) calculate the equivalents of drag and weight. . . . These are things that can be shifted back and forth. You consider them as a unit quantity, which you might say is efficiency.

General Kelsey: There is another aspect of this. The problem here is holding air speed, and it is sort of pathetic that we have air-speed indicators and power controls and that there is no way of getting the two together. There is a challenge to the industry and the rest of us to bring out these indications in forms, power circuits, and outlets that we can apply to other inputs or input sockets, if you will, which will enable us to use them.

The basic element of this, it seems to me, is: "Do we put in some circuit that automatically removes from a pilot or a crew the means of observing operation and perhaps correcting it or monitoring it?" This is not necessarily true. But there is no reason why you must have an air-speed indicator showing a given figure and have some member of the crew watch this and manually move a lever. This response is so simple mechanically that it should be applied directly, with the crew providing a judgment control on top of this. . . .

When you stop to think of instrumentation, we have some few things to hook together. We don't have standard outputs. If we want to have a pilot input, that has to be built into the autopilot. We can't pick air speed and put that in, because there is no compatibility.

The essence of this thing, probably, is not can you build the airplane to do it without it, or do you have to have it, but how do you match these things so that, if you want to do it, you can do it right now or in the future without getting into complications?

Mr. Klein: What you are asking for is a metering injection carburetor. This is a mechanism that does exactly that, and it has no power to it other than the fuel pressure.

General Kelsey: That was one of the things we found on an automatic flight. We found a great many of them which you could short-circuit, and you got direct response elements that took care of themselves with remarkable simplicity. You didn't anticipate it until you separated these things and made it possible to get any combination.

As a typical illustration, one of the things that pays off is pulling up the landing gear. In some cases, being able to pull up the landing gear in heavy flight configuration is a valuable asset.

Mr. Milliken: It seems to me that a particular damper developed and used is practically the coupling

device you are talking about. In other words, the damper picks up air speed, or some other indication in the airplane, and simply moves a tab or small surface or something to give you the necessary damping.

This is an extremely reliable device. Furthermore, if it quits at any point in its operation or if the thing should go bad, it still could not do anything to the airplane which would be appreciable. You are simply trying to put damping into oscillation, which has essentially no damping.

I personally feel that, if Mr. Klein were faced with the problem brought up by Mr. Pike—of putting in a little bit of damping—he would have to wind up with a damper of this type.

Mr. Klein: This is a simple mode of operation. This isn't damped. But what the other thing is, I am not prepared to say. It is electronic right at this minute. I would like to think of other ways of doing it first.

Mr. Guyzer (Boeing): We have all been fairly engrossed in being engineers for the last 5, 10, 30, 40, and in some cases, 50 years. By now, most of us know how to design at least one item and do a pretty good job of it.

We have been emphasizing the learning process for the last 5 or 50 years on learning how to design. As yet, practically no thought has been put on the business of the theory of maintenance or the theory of what causes failures. It seems that each member of the panel to one extent or another has commented about reliability. It seems that now is the time to sit down and do some serious thinking about what the basic cause of failure is or what the basic theory of maintenance is. We are at the point where we can build things. All we have to do now is to make them work.

Mr. Draper: I would just like to mention again that reliability and how you get maintenance are prime problems. You can make a gear that works. To make a gear that will work under conditions of operation and will provide within itself the means of determining what has gone wrong if it does go wrong and to bring it up so that it is easy and simple to fix (from the standpoint of maintenance) is the primary objective.

I intended to make this the main theme of my remarks—namely, that this is not an impossible thing, but that you do have to give the same kind of thought to it that you would to the maintenance of your engines, etc.

Mr. Ciscel: I cringe a little bit every time I hear the word electronics used with respect to automatic pilots, because there is a great deal more to it than just electronics. The tubes are part and parcel, and we feel in working with them that there is no point in pretending that they are sheep and that the rest of the equipment consists of the goats, or vice versa. The system as a whole is designed for reliability.

Mr. Klein: The most important characteristic that I have observed in engineering departments is the psychology of the design group. I have never known a successful design to come out of an optimistic attitude in an engineering department. Every really successful design I have ever seen—and this is regardless of what the design was about—was in a group that was always scared to death, afraid that the thing wouldn't work—they were anticipating failures and defects.

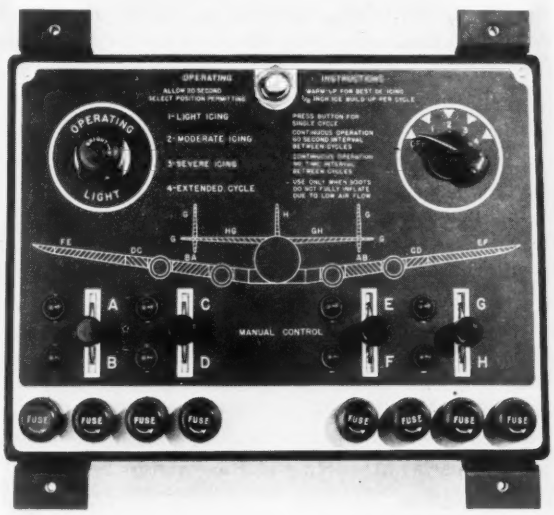
The most successful autopilot I ever saw was designed by a man I am sure all of you know. He was involved in a bad accident, flying in a B-29, and they had a fire. A washer fell into a junction box, and they lost the entire electrical system. They had the landing gear down. They had the props down and in the lower r.p.m., and the airplane wouldn't fly under these conditions. They landed in Puget Sound, and he had to swim for a distance of $^1/_4$ to $^1/_2$ mile with three broken ribs.

This man has designed the best autopilot, with the smallest number of tubes of any. That is because he realized that electrical failures occur in airplanes. . . . This man has a sound attitude toward autopilots. He just doesn't use push-pull amplifiers in them. This may be good electrical practice, but it isn't good aircraft practice. . . .

This attitude toward the design is, I think, the best single criterion. The attitude must be that the apparatus is inevitably going to fail and going to be "mismanufactured."

Chairman Warner: I suggest that we turn back to Mr. Hunsaker's question. As I recall it, correctly paraphrased, it was this: Are we within the prospect of having to regard the automatic pilot as being so indispensable to the airplane that we must provide the necessary designed elements and duplications to ensure that it will never fail?. . .

General Kelsey: I think the answer to this is negative. There is no reason why it shouldn't, eventually. On the other hand, I think there is some validity in Mr.



Courtesy Eclipse-Pioneer Div., Bendix

Electronic De-Icer Timers are used to operate deicer boot inflating valves. The electronic timing circuit determines the duration of the boot inflation and, during automatic operation, the rate of repetition of the complete cycle in accordance with a predetermined schedule.

Klein's position—that there is no reason to use this as a crutch for failure to investigate basic characteristics and that there is a tendency in many of these things to use supplementary items of this sort as a crutch. But as an inherent part, as Mr. Draper puts it, designed basically at the start, there is no reason why it can't be incorporated.

One of the questions that came up earlier was: "Can we depend on this in the transonic region?" I replied by saying: "Don't use it if you get into a place where it puts you into worse shape than you otherwise would have been in." Perhaps you could modify that to: "Don't use any single item to extend your range of operation to a point whereby it automatically puts you into a position from which there is no retreat."

Perhaps an automatic pilot or flight is too large a system to talk of as a unit. But if you couple these things up with inherent stability and control, with multiple reserves, it is entirely possible that you can use any one of these elements to a reasonable degree.

Chairman Warner: Mr. Pike, I pass the same question to you. I think you said that the existing jet transport cannot be flown satisfactorily without the automatic pilot, but I gather that it can be flown with the automatic pilot. Do you foresee the possibility in the reasonably near future of being unable to operate satisfactorily (or safely) without the autopilot, so that you would have to assume its continued operation as a necessary part of the aircraft?

Mr. Pike: That is a difficult question, but in the near future, I would say, "No." Air-line operators must make provision for failure, and if we carry the argument to the extent that we have to have a completely satisfactory autopilot that will never fail, we shall pay an economic penalty that will destroy the value we get out of it.

It is a mistake to regard the autopilot as something that will replace the human pilot at this time. From the standpoint of the air lines, we should regard the automatic pilot as helping the human pilot to use his judgment in doing a better job. If you do that, you may design autopilots that are going to work better, particularly, if you don't try to make them do too much.

Chairman Warner: Mr. Hunsaker, would you like to add anything to your question?

Mr. Hunsaker: I don't care to ask a question, but I would like to make an observation. If we take the position that an airplane ought to fly safely without the automatic controls, we limit the performance of future aircraft. We are merely using the art of automatism as a kind of auxiliary to help out. Maybe if we were to go the other way and use them to achieve a type of performance that could not be obtained otherwise, then we would have to depend on these devices as primary parts of the flying machine and its system.

Mr. Milliken: It seems to me that fundamentally we wouldn't be talking about putting electronics or automatic control on aircraft unless we had two reasons. The first is that there must be something about the basic aerodynamic aircraft which needs fixing up. Second, the operational jobs that we are asking of the present-day airplane are more severe than we have ever run into.

In an effort to get to the bottom of this particular problem, we have applied automatic control, or rather, artificial stability, on a particular airplane to the extent that we have removed all of the bad qualities of the basic aerodynamic airplane.

In other words, we have built an airplane by use of this particular research equipment in which there are no oscillations and in which the airplane has no divergences. With this aircraft, we hope that we will be able to answer very basic questions. In short, for the first time in the history of flying, shall we say, we have what is a really good airplane. We beheve that with this good airplane, we will be able to do difficult tasks or, at least, tasks that heretofore have been impossible without considering fancy types of automatic controlling systems.

I don't think that the average individual, or even the pilot, realizes what a poor flying machine a conventional airplane is. If you put automobiles on the road, for example, which had as little damping as the airplane does and which had large differences in damping between the motion about different axes, you just wouldn't be able to sell the automobile to the general public.

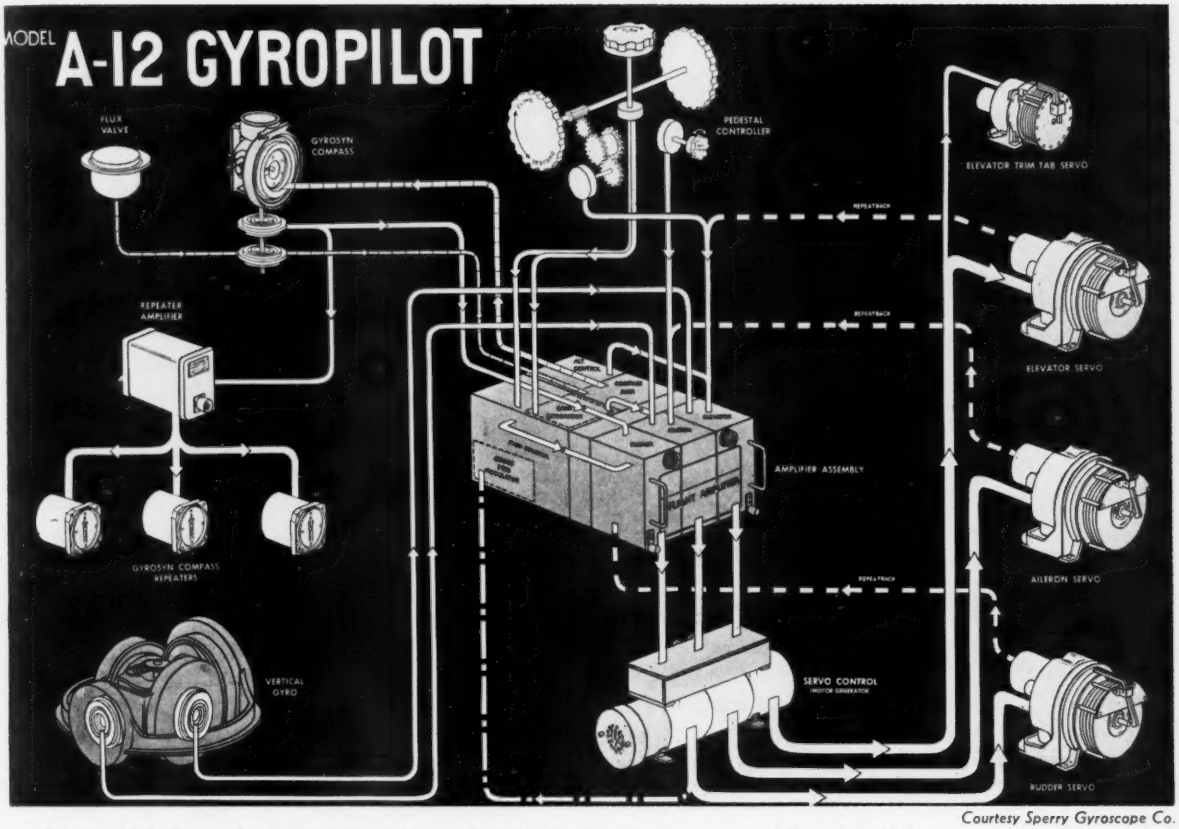
I think that the pilots for many years have acted more in the capacity of supplying artificial stability to airplanes then, shall we say, in the capacity of supplying overall guidance. They have supplied a little bit of both, but they certainly have spent a great deal of their time ironing out deficiencies in the basic aerodynamic airplane as we know it.

Captain Jensen: I would like to comment on Mr. Hunsaker's latest remarks. I think the discussion of reliability has pointed to the fact that we would like to master one art before we move on to the next one. I don't think we want to step into the range of both control and design for it until we can use this control as an aid and an assist. Once the reliability and acceptance of that is proved, then we are ready to go on into the next step. I think the engineering profession should be leading the field and should be thinking about that next step. But we should not jump ahead of the game and miss the present step before it is solved. . . .

Mr. Goett: We have found in these stability flight tests that we have been making that the pilot is a surprisingly adaptable creature. It is hard to make the airplane so bad that he can't fly it. . . .

We found in a surprising number of instances that we could take directional stability away from him, and he still could track as well when he didn't have it as when he did. The big difference was that he knew he had been working after it was all over. On the other hand, if he had normal stability, it was a lot easier for him.

Therefore, I would say that we might use these devices so that, while they are working, we would get the objectives that Captain Jensen asked for. If the de-



Courtesy Sperry Gyroscope Co.

Diagram of the Sperry A-12 Gyropilot illustrating elements of automatic-pilot system and flow-of-signal data among the components.

vice fails, he has an emergency condition, of course, but he works hard, and comes home and manages to land. . . .

Personally, I feel that the airplane as we know it, is a pretty good beast. Instead of attempting to improve it and make it still better by these automatic devices, we should merely use these devices in place of something aerodynamic, and when the thing fails, the pilot just has to stay within the tolerable operating range.

Mr. Draper: The way I look at this business is that you have two problems. You are going to fly an airplane, and that is a complete job. The first part of the job is to reduce the effect of interferences from rough air and instability to a certain extent so that you can do the rest of your job.

Then the airplane, in effect, must receive certain commands that come from the outside. These commands may be based on following a radar beam, or landing beam, or might even involve some type of fire-control problem.

There is the problem of "tracking" some kind of a target. This presents a different problem, because, if you are going to do a satisfactory job from the standpoint of fire control, you cannot allow the direction of your aircraft to wander more than a small fraction of a degree.

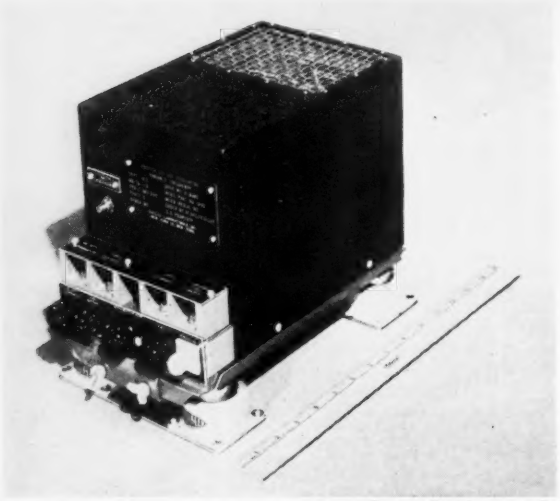
So let us talk about something that is really not pilot relief. Let us talk about something that perhaps contemplates that he is really getting some assistance. Let us consider the problem of the fellow who is turning out an accurate fire-control job against some kind of a ground target in the presence of rough air. . . . It seems to me that perhaps this area is one of the places where the essence of automatic control begins to show up and be an important thing.

Chairman Warner: We have heard a considerable amount about the disadvantages of using automatic control. We have heard relatively little about the advantages of using it—at least on aircraft that have inherent stability and don't need the artificial kind to the extent that it enables the pilot to pay more attention to his job. I would like to hear more about the other advantages, assuming that there are some.

Mr. Pike, will you say something about the automatic control of economy operation or loads applying to turbulent air and consequent comfort?

Mr. Pike: On economy, I have mentioned the penalty we must pay through failure to maintain the optimum incidence. In other words, variations of attitude are causing us air-speed losses.

Take the air-speed loss over the sector we are operating at the moment. We are operating about 10 m.p.h. from the optimum. That would represent a pay-load penalty of about 700 or 800 lbs., which means several passengers. You must bear in mind that you never carry a pound more fuel than you have to, because it costs you about half the weight of that extra fuel to carry it. . . .



Courtesy Ford Instrument Co.

An electronic subassembly for an air-borne computing device which combines accessibility for maintenance with compactness of size.

There is one other thing that is pertinent to this question. I mentioned the importance of the quick recovery. With the jet, you haven't got a constant reserve of power, and it takes three or four times as long to recover with the jet than it does with a piston aircraft. Therefore, undoubtedly, we should get much benefit from perfected automatic control.

Mr. Little (American Airlines): Speaking with reference to domestic air carrier DC-6's, I am of the opinion that a modern electronic pilot, with properly operating altitude control, will (under the average weather condition flights) keep the aircraft on its "step." Our experience has shown that you wind up with about a 10-m.p.h. speed advantage if you have a properly operating autopilot at a 300-m.p.h. speed. . . .

Chairman Warner: Have you anything you can add on the matter of turbulence?

Mr. Little: American Airlines completed a contract on thunderstorm research. As I recall it, the N.A.C.A. measurements showed that, under automatic control, you put only one-third the strain on the aircraft structure that the experienced air-line pilot would put on the same plane without an automatic pilot.

Audience Member: I would like to inquire what type of pilot that was. On a theoretical basis, the altitude pilot would produce more strain and the acceleration autopilot less.

Mr. Weisenbacher (American Airlines): This was a Sperry job.

Northwest Airlines Representative: I am wondering what the philosophy in the future should be. We have currently reduced autopilot forces to the point where they will not fly the airplane. They are safe, but they don't help you at the time you need them. In order to get interchangeability of components, you must assume accumulative tolerances, and you must come out with forces that are unrealistic.

It is my opinion that, if this trend continues, we might as well take autopilots out of airplanes, because we will never do a job of work that will be acceptable in the type of operations that you have from day-to-day air-line service. If it takes the pilot to fly the airplane, you ought to give the autopilot the same job that you do the human pilot.

I wonder if these American Airlines tests were made with the 1*g* limitations and the 40-lb. wheel-force limitations, etc. I don't believe you currently fly thunderstorms consistently with the present forces that you have from day-to-day use.

Captain Jensen: I think this problem comes back to Mr. Draper's comment that we need some more system engineering for airplanes. In other words, call all of the people involved in aircraft design into the picture more so than they are now, so that the autopilot manufacturer or designer is in complete coordination with the air-frame manufacturer, engine manufacturer, etc.

Mr. Klein: I was told by our autopilot expert just before I left the Coast that this situation has improved somewhat. But I would like to point out another thing, and that is that, if the pilots would drop back on their force requirements, we could do a much better job in this regard. The trouble is that the inertia of the control surfaces is one of the limited requirements. With the low forces that the pilots asked us to build into the airplane, which we achieved with great difficulty, it is hard for us to work with these autopilot forces to get them to move the surfaces rapidly enough against their inertia. These forces are requested by the pilots and are not set by the engineering group.

Mr. Ciscel: There has been a series of questions that I think we could do well to look at. The Northwest Airlines representative asked about the forces, and whether or not that was all we were doing? Historically, the requirement for the reduced forces on autopilot servos came about as a result of the crash of an airplane some 3 or 4 years ago. The outcome of that was a definite requirement that autopilot servos be reduced.

This is something that could be done with resisting equipment. The implication that it would be the only solution was never accepted by the people in the autopilot industry. We have many other types. We talked a little bit earlier about limiting servo travels, and doing other types of monitoring, in the hope of bypassing this problem you have mentioned—i.e., that of reducing the servo-torque to a point where it is safe. But it is also ineffective. . . .

We also mentioned that there are worse things that can happen than have hard-over control signals in the surface itself. You can build up attitudes and rates of descent which are also something to consider in other ways than just limiting the control of the servo or the torque of the servo.

As a result, looking toward the future of automatic pilots, we are coming up with these other types of monitoring and different automatic pilots. One is a differential type of autopilot, where the servo puts in small corrections differentially. It by-passes this problem of maneuvering through the autopilot, because the human pilot maneuvers his own controls.

All of those things are definitely coming along, and I think they will be much better and sounder solutions than this one of just rendering the autopilot ineffective.

Mr. Adams: Another restriction that has been put on autopilots, which seems somewhat unfair, came to my attention a few years ago. Pilots, when landing, do make noncoordinating skid turns when they are close to the ground, not quite in line with the runways, and the weather requires it. Otherwise, he would be delayed in landing. . . .

So here you have a situation where the pilot may beat the autopilot because he has different ground rules.

Audience Member: I don't quite agree with you that the pilot can beat the automatic pilot. We at All-Weather have shown on a number of different systems that you can get about twice as many approaches within the runway limits with automatic approach coupling than you can by using the human pilot.

Mr. Draper: In line with this, we found that, when the human pilot was really working at it (putting full attention on it), he could do almost as well as the automatic pilot or automatic gear for 3 or 4 min. But if you tried to make him do it for 15 or 20 min.—or if he was giving any attention to anything else—he could not do so well as the automatic pilot.

Of course, we are talking about different kinds of aircraft—fighter aircraft. But that is the way it worked out.

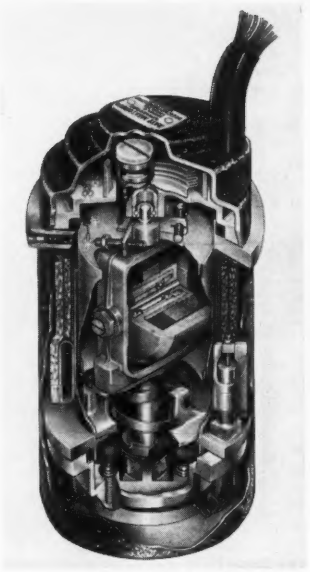
Mr. Wenner: Assuming that you can meet all of your requirements as to reliability and the system is fail-safe, what is going to happen when we are met with enemy aircraft taking the risk of flying in regions we can't reach without automatic control?

This is one of the things we are faced with and it is strictly a military problem. We can't restrict ourselves to regions where the human pilot can handle it with some risk in higher speeds or with more maneuverable aircraft.

General Kelsey: That brings up a whole new field—that is, battle damage area—the accident induced by someone else's intent. You have reliability not only of equipment, but you have reliability of a mission in the military sense, and you must couple both of these things together. Having committed a given piece of equipment and a given crew to a mission, its failure to accomplish the mission may be the result of a great many things.

One of them is its inability to fly precisely enough, let us say, and the other one is exposure to malfunction of equipment. Another one is exposure to enemy action.

To illustrate one of the things which we were talking about earlier, there were bombers during the war that were flown so badly out of trim that a small piece of flak, for instance, would cause the loss of the bomber. I have actually seen them go into a loop before they could be caught. You lose a bomber on account of this. You can't extend your operating range in "trip," for instance, through servos and artificial stability inducing forces, carrying them on pieces of equipment which themselves are invulnerable to such an extent that you lose the reliability of the mission.



Courtesy Doelcam Corporation

Cutaway view of the Model K Rate Measuring Gyroscope which has found wide application in providing derivative damping and control signals for guided-missile and aircraft stabilization.

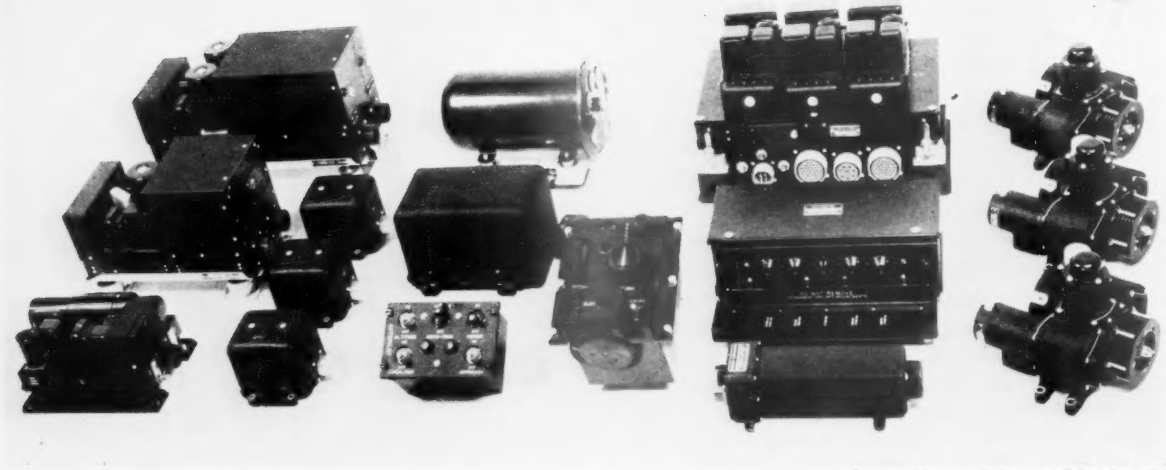
This doesn't mean that you can't use servos. It doesn't mean you can't use automatic control or artificial stability. But in the design, you must include features that will prevent the enemy from being able to multiply the effect of his attack to cause a loss of that mission. At the same time, you will have to provide a certain risk or take a certain risk in order to provide performance that will enable you to accomplish the mission.

This thing also goes into bad weather. If you multiply the number of times that you can fly, regardless of weather, by some factor, it is a thing that multiplies the number of aircraft in operation. So the whole picture has to be evaluated, as well as the reliability of any piece of single equipment.

There is no answer to this. But I think you can see it is essential that we consider this business in terms of not exposing ourselves to a multiplication factor in which, perhaps, the damage by enemy attack is more serious than anything else we can have.

At the same time, you do have to balance this against performance. You must have comparable performance in this competition. But that involves risk with equipment that has a certain amount of unreliability. You have to take that, too. After all, when you are up there shooting at somebody, and he is shooting at you, it is not very safe anyway.

Chairman Warner: I would like to ask some of the operational people how grave the obstacles are in their opinion, aside from doubtful liability, which would stand in the way of routine use of the automatic coupling in the approach. Would you be ready to use any type of automatic control that can now be produced as a regular aid to approach?



Courtesy Minneapolis-Honeywell Regulator Co.

The components of the MH-11 autopilot which provide automatic stability, yaw damping, altitude control, air-speed compensation, and approach control.

Captain Jensen: Briefly, it is obvious that any pilot is going to accept anything that will assist him. In other words, if the coupler is reliable and will assist him in his job, he is for it. That is true of any other piece of equipment. The pilot wants any assist that he can get. . . .

Automatic couplers, properly functioning, are going to increase the reliability of our schedules. This is naturally an economic factor that is going to pay for a lot of automatic couplers, and I don't see anything that would stand in the way of their use.

I think it is obvious that a piece of equipment that can spend its full time guiding the aircraft through the runway is naturally going to do a better job than a pilot whose attention is diverted.

Chairman Warner: Mr. Pike, you have heard about automatic couplers. Can you add to that?

Mr. Pike: First of all, you must consider what is the limitation on the present development of automatic couplers. It became obvious to us that, if you are going to use the pilot for a long time as a safe device, he has to be provided with certain visual guidance in the approach to land the airplane.

One of these days, we will take a jump, militarily first and civilian later, but in the meantime you are up against a certain limitation—the reaction of the human. The time requirements are such that you require certain visual guidance to land the airplane, and there is always some uncertainty. Therefore, you must have a certain safety cushion in there.

There is a figure of visability below which we as air lines would not be prepared to operate until the time comes when we can accept fully automatic landing. There is a further factor that becomes important when you start getting down to these low minimums—that is, the labor of the airplane itself. We do know now that we are far more limited by the bad qualities of the airplane than we are by some of the aids we have spent so much time in discussing here.

If we can get airplanes of lower approach speed—where the pilot could just press a button and everything would happen at once and at exactly the right rate—we could carry out the kind of maneuver that we can do regularly on trains with touch-and-go landings. Then we could come down quickly.

Therefore, we feel that a little more attention of the designers to what I might call the approach in the landing requirements of air lines would be worth while. It is one of the things we think is lacking.

Mr. Adams: There is no doubt that, if you want to use automatic control to land, you should change landing gear. You should change the ability of the airplane to steer without banking when it is low, because otherwise you are limited.

Here is what actually happens in autopilot approach in experiments we have made. We have arbitrarily said that the autopilot cannot bank the airplane to such a degree that, if this were the last-second jump down, the wing would be as low as the tire. We haven't any adequate way of knowing which is the last second, and therefore we have to act as if each second were the last. . . .

If you are not allowed to bank or skid, you are stymied. The autopilot needs more freedom to maneuver the airplane the way a pilot would. You also need an airplane with a longer stroke landing gear before you can come to really automatic landing. . . .

One of the big limitations now is the fact that we have, to quite an extent, allowed aircraft to get off the path. . . . It takes a great deal of time—something like $^1/_2$ mile—if the airplane is off about 50 ft., to get it back on the same flight path.

Therefore, one of the big problems is to make the airplane better, and that should ultimately be done. In the meantime, weathercocking—long before the air-

plane gets off the path—may give the wrong heading but never the wrong position. You can make some good low approaches under these conditions.

Chairman Warner: General Kelsey, would you care to comment on the rate of progress toward automatic landing, and what the prospects seem to be?

General Kelsey: I would like to get at the other angle first, because I think this thing is primarily not due to the technical performance of the airplane but to the psychological barrier. One of the things that bothers pilots is that the autopilot brings along with it a tradition of the darndest sets of knobs and gadgets and controls that anyone ever created.

The pilot has to take his attention away from what is primarily his job of monitoring and controlling in order to run a new and unusual set of controls. If you put in an automatic coupling you again hook him into an almost irretrievable position. This is psychological—not necessarily actual. . . .

I suggest that one of our design problems is not necessarily the technical performance of the equipment but the presentation of these things to the operators in such a way that they will feel comfortable about it. One might suggest that we could put everything in a stick, which the military pilots hold normally. . . . If the coupling is automatic, the pilot doesn't have to change hands, and he monitors things in a perfectly natural manner. I am sure you would have many fewer objections in this case.

It is this feeling that you have jumped into cold water, that it is either sink or swim, that there is no time to correct it, and that is as much a barrier to correct it—it is not the barrier itself.

Chairman Warner: Does anyone wish to reply to what has been said about the responsibility of the airplane designer?

Mr. Klein: I agree thoroughly with Captain Jensen—the big trouble today is the insecure position that the pilot is in. . . . Instrument boards don't look alike. Everytime we have to lay out a new one, it comes out differently. . . . The pilot has the feeling that the reactions are presented to him in an unnatural manner and contradict his life-long training on what he should see.

A few of us have been promoting for years a hypothetical blind landing system. This is completely hypothetical. This system would involve a radar that would give the pilot a picture of the field in something like an overgrown machine-gun sight in the windshield. . . .

If this objective is ever achieved, all of these problems we are talking about will disappear, because the pilot would be landing his airplane, psychologically, in exactly the same way as though he were looking at the field normally.

Mr. Pike: There is a lot of development going on along these lines. I am not an expert on visual aid, but I think perhaps one of the difficulties has been that the known visual signals that we get and interpret are different from the physical signals. According to scientists, the answer is training pilots with the same type of information.

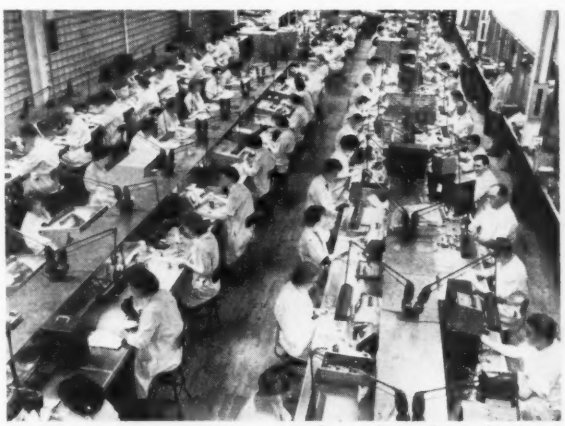
We have been trying to find out how a pilot does land an airplane. But one interesting thing is that he does treat the airplane as a projectile, and he aims at a point once he has established it. Perhaps, if we borrow that principle and find out from the pilots now how important they think runway markings are, we may get a clue as to what their real requirement is.

Captain Jenks (C.A.A.): In my paper (presented at the I.A.S. Air Transport—Safety Session), I try to lead up to this. The main thing is to achieve straight-line flight. Any pilot can tell you that straight-line flight is one of the toughest things to do—particularly when it is a predetermined straight line—because the only way you can fly it is to bounce back and forth from one side to the other. The less you bounce, the straighter the line.

What I mean is, if you turn 5 deg., it takes time for that turn to develop. Once you have turned 5 deg. and have stabilized on a new heading, you have a certain rate of displacement. Somewhere along the line that displacement brings you back on your track. We have got to throw another turn, and that takes time. Once it is stopped, did you overstop it or understop it?

These are all the things that the pilot has to take care of, and when he is doing it with just a mounted instrument on the panel, it is a rough job. When you are flying visually, you can see where you are going. You furnish the rate ray, and you know what the ray rate is, and you can see it. In instrument panels, it is strictly an amount, unless you have a coupler. When you get into couplers, the problem there is setting rates for any given conditions.

(ED. NOTE: *A movie was presented at this point by Mr. Milliken which demonstrated some flight experiments carried out at Cornell. A particularly unstable airplane was fitted up with a yaw damper and autopilot instrumentation so that completely automatic flight was achieved—even under stalled conditions.*)



Courtesy Eclipse-Pioneer Div., Bendix

Tiny Autosyn synchro-type devices, which serve as nerve centers for the complex remote indicating and control systems aboard modern aircraft, have to be produced in immaculate, temperature- and humidity-controlled air-conditioned rooms.

Chairman Warner: Assuming that we get past our problems of reliability and assuming that the auto control is to be counted on, how would it affect airplane design if we did rely on artificial stability, and how much would be gained by it in reduced weight or drag or otherwise?

Mr. Klein: I think there is no general answer to this question. In some airplanes, such as Navy types that are restricted in length by artificial requirements, there is difficulty in achieving stability because of the short tail length. In these planes it might be possible to reduce the tail-surface sizes to that of the tail alone if you had trustworthy stability, etc.

On the other hand, there are planes in the transport class where the fuselages are sufficiently elongated in order to get in a large number of passengers, and in these cases the tail-surface size may be proportioned by control. In this case there will be comparatively little advantage achieved.

Mr. Draper: I think it was Mr. White from Boeing who presented a paper to the Institute some 2 years ago on the use of a yaw damper. I believe his estimate was that it would require 50 per cent increase in the vertical tails to provide the amount of stability he was getting out of a yaw damper. Just how much weight that was equivalent to, I don't know, but it sounds like it would be quite a bit.

Mr. Milliken: The British had some experience with a yaw damper, in which they found improvement in the rough-air qualities which would lead one to believe that the yaw damper is probably one of the first or immediate practical devices that we have on the shelf which we can use to improve the riding comfort of the aircraft. It certainly is a far safer type of device to think of than some of these gust-alleviation systems that seem to alleviate flaps, etc.

Mr. Cannon (North American): I would like first to go back to some points that were made by Mr. Draper and General Kelsey. These gentlemen brought up the point that a successful automatically controlled flight system will require that the fundamental design of the air frame be conducted at the same time as the design of the autopilot—that is, that the autopilot and flight-control engineers should be in together on the basic design of the airplane. . . .

I would like to add that this would give the autopilot people time to design an autopilot that not only met the specifications but also had a far greater degree of reliability and simplicity than could ever be secured with the type of programing we do today.

Mr. Goett: On this problem of matching the autopilot to the air-frame system, there are always the questions that arise: How accurately do you have to represent the airplane? How complicated must the equations be? What are the important derivatives? Mr. Adams mentioned something about the use of computers for this purpose, and there, of course, you have to put in something to represent the airplane.

If you are going to do this far in advance, it means that you are going to have to do it with derivatives that you got in a wind tunnel, because you can't wait until the airplane is flying.

[ED. NOTE: *Mr. Goett then showed a series of five slides, indicating work that had been done in this connection by N.A.C.A.*]

Mr. Ciscel: On the off-chance that some of you may have gathered an impression that we are having difficulties as automatic control people in getting together on the need for artificial stabilizers or integration of systems, I would like to summarize our position.

(1) On artificial stability, it can be established that it is no longer a point of academic discussion. The thing is here. It is accepted. Aircraft that are going to carry artificial stability are being equipped with artificial stabilizers, yaw dampers, Fitch dampers, or whatever they happen to need. All of those airplanes are being designed to give a certain type performance with the use of artificial stabilizers.

This does not hold true, necessarily, for commercial air lines. But it is certainly true as far as military aircraft is concerned, and it extends through all of our crafts and bombers and some helicopters. . . .

(2) There is the recurrent suggestion that automatic pilot people and airplane people should get together. That is a situation that has improved tremendously in the postwar years. Big things have happened as a result of the general dissemination of automatic control theory. People became aware that automatic control equipment was not just something that was bolted into an airplane. . . .

The amount of cooperation we are getting today is simply fantastic, compared with the standards that prevailed during the last war. . . . We are now able to get what we need over the entire speed ranges not only in terms of aircraft coefficiency necessary to run react analyses but also in terms of all the limitations we are worried about on allowable difficulties.

(3) What are the autopilot people doing to further improve safety? I would like to say again that we are working on these things suggested by members of the panel. . . . We have high hopes for eliminating some of the artificiality of flying through an automatic pilot.

After all, that harks back to the day when they put an autopilot in to hold the airplane still while the pilot was doing something else. Now it comes to the point where the automatic pilot can do certain things under certain conditions and the human pilot prefers to fly with it.

Chairman Warner: Mr. Draper, would you care to say what you see as the next stages of development, and what the future uses are going to be?

Mr. Draper: I have a feeling that we are going to end up with this integrated flying entity—with controls, the sensing elements, the power elements, and the interconnecting elements (which may be mechanical, hydraulic, pneumatic, electrical, or anything else)—and that this whole collection of equipment is going to be so reliable and so insignificant, compared to the rest of the

airplane, that you will get around to the point where you will not even know it is there. . . .

Also, I have an idea that this business of a natural or unnatural control from a pilot standpoint is going to be something that becomes less and less important as time goes on. The human being is going to be there. He is going to have the information laid out before him in a considerably simplified form. . . .

I have a feeling we are going to end up with flying devices that, if they carry men at all, are going to be merely monitors and exercise the function of judgment. Certainly, the number of flying devices that have no men at all in them is going to increase, and they are going to do a much better job than the ones in which you have the men present for special purposes.

Captain Jensen: I would like to sum up the civilian standpoint and perhaps inject a couple of thoughts for you to take home and think over. Let us take the reliability situation for a moment. I think we all agree in the operational field that we ask for the Moon. It is probably a good idea. We say we want a perfect machine and hope we can get one sufficiently toward perfection that we can live with it.

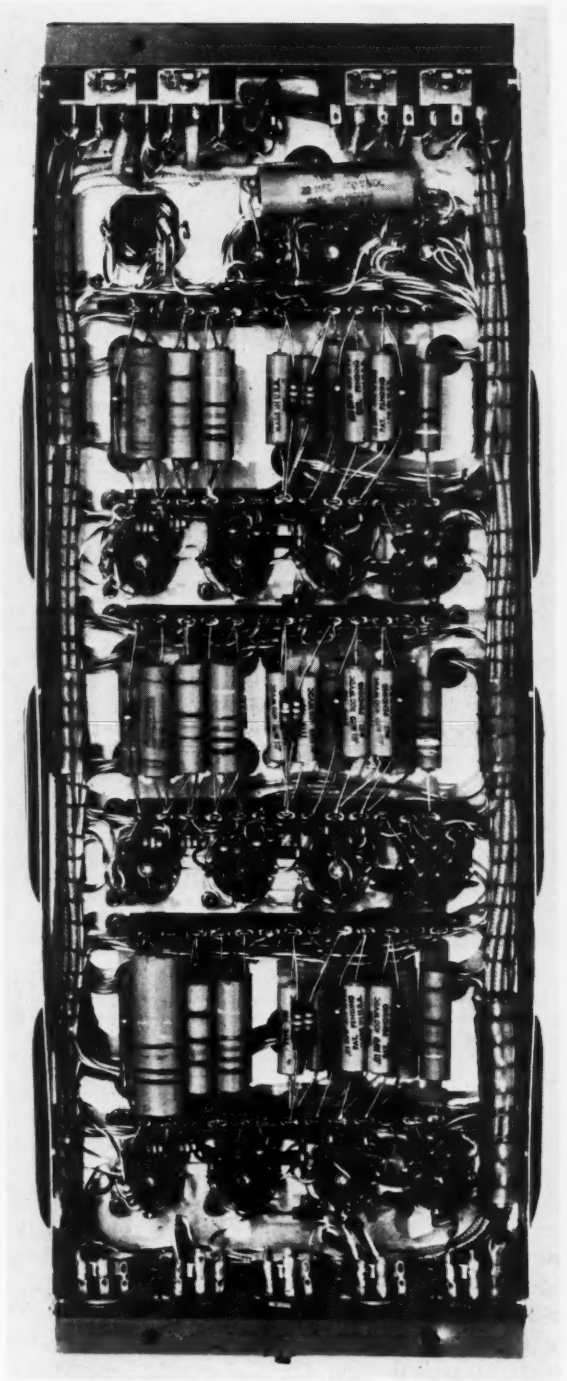
In that respect, I think there is a job to be done in some agency, or groups of agencies looking at the aviation job in all its aspects, to properly bring the matter of safety into a common denominator. In other words, look at the various components of the gadgetry that we fly with and all the corollary operations to flight, and find out whether we are being overly safe in one operation and reckless in another part of the operation; whether we are being overly worried about the fact that the automatic pilot is unreliable; and whether we are carrying two communication receivers where one would give us the same degree of safety that we are accepting from the pilot's experience and training. . . .

I have a sort of pet notion on how you might look at the safety situation. . . . I think you might assign an arbitrary figure—say 100 points—that add up to an accident. You can then assign certain values for different abnormal situations.

You might figure that an engine failure is worth 5 points toward that 100-point accident. You might say that, if the pilot isn't speaking to his wife, that might contribute another 5 points. If the landing gear failed to retract, you might add another 5 points toward the accident.

In other words, accidents are not produced by any one item of the 100 points occurring at a certain time. It is a combination of events. If the automatic pilot happens to fail under certain combination of events, it may be no problem whatsoever. It is the combination that produces the trouble.

You can sit off in the corner of your portion of the aviation industry and say: "We have a failure rate of such and such a percentage." It may sound good. But under certain conditions of flight, certain combinations occur at which the failure of the component in which you are interested happens to contribute the last 3 points toward that 100-point system that causes the accident.

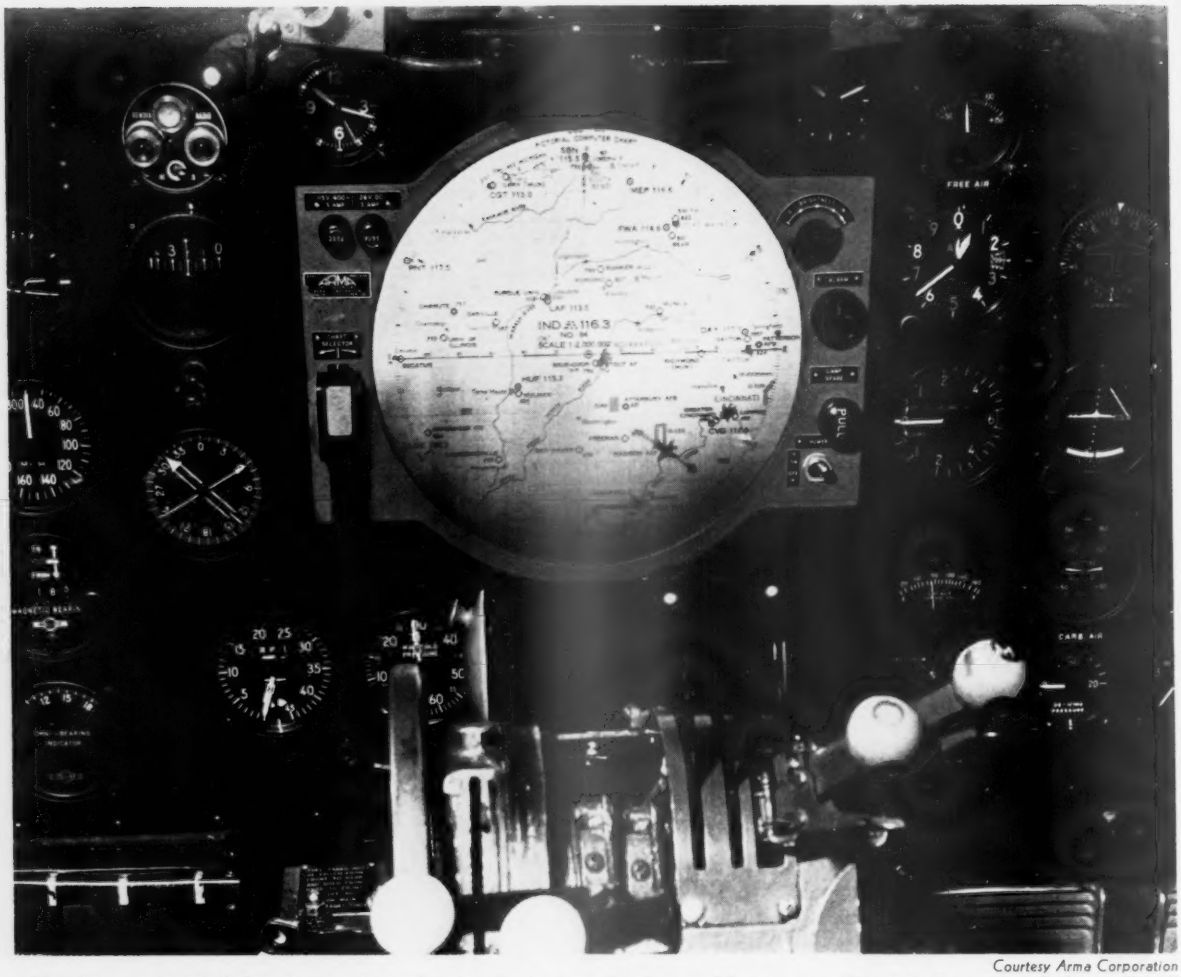


Courtesy Lear, Incorporated

Underside of amplifier, used in Lear L2-5 autopilot, showing electrical circuits.

Mr. Klein: The problem of automatic control of aircraft, I think, is essential in the military world—that is, both the fighter and the bomber will require a complete automatic direction for purely military reasons.

As far as autopilots are concerned, I am confident that they will become a reliable and useful device.



Courtesy Arma Corporation

Visual computer, installed on instrument panel, gives plane's range, heading, and bearing on self-contained navigational charts. "Bug" *(lower right on screen)* is electronically synchronized to "crawl" across illuminated chart, thus giving pilot his position at all times. Charts, projected from film strips, are drawn in four scales and are immediately accessible through a selector control. OBD computers are automatically tuned to station shown on chart.

They certainly have taken a beating in the last 5 or 10 years, which usually precedes the solution of a basic problem. These problems are now fairly well realized, and something satisfactory should come from it.

As far as the approach and landing system is concerned, I am firmly convinced it is on a totally incorrect, unsound, and illogical basis. . . . It does nothing about the collision problem with other aircraft and with other obstructions around the field. I feel that we must replace the pilot's eyes. We must give him eyes that can see through the bad weather conditions. There are means available in the radar field to provide him with a windshield that sees through darkness and obscurity.

I feel that this is the only way that we can get around the landing system, because then it becomes a visual system, and all these problems disappear.

General Kelsey: Several years ago when we were first trying to explain what we were doing with automatic flight projects, we had some newsmen in and explained this business of a preprogramed flight. We tried to describe this. We talked about pushing a button in Chicago, and not worrying about it until the plane came to Chicago. That was all right. We could do it with a model. We explained that with military operations you have long-range missions that you can calculate ahead of time in relative calm and quiet—letting the airplane follow this preprogram course and using the human element to provide the machine with the facts.

One of the newsmen piped up and said: "Well, can you get to the place where you can punch this thing out on IBM cards and put it into the airplane and sit there and watch it do it?" He came close to defining what we are talking about. This is not very far off.

However, one of the things that becomes apparent immediately is that, many of the things you can do automatically, you will find you don't want to do because it is uneconomical. There are many things a man can do better than a piece of machinery. It is unnecessary to try to do it the hard way just to be automatic.

One of the things that you can prove quickly is that this must be a matter of some discretion. We find in the missile field, which is the push-button warfare thing

everyone has been talking about, that there are a lot of loose ends in that, too. The essential element there is whether you can use a preprogram flight that doesn't require correction once it is dispatched. . . . However, you will find that many of the elements that you develop with this immediately apply to monitor flight in which you want to retain the possibility of correction.

One of the things which appears to be stalling us today, and which we will have to have corrected in the future, is that many of the things brought into the cockpit now which require manual control are loose ends of an individual project. You find that many project officers and engineers have come to their wits end and have brought in the control switch or throttle because they couldn't figure out what else to do with it.

It becomes the pilot's job to mix these elements. Before we can progress in the future, we are going to have to find ways and means of taking loose ends and tying them together or cutting them off back at the source so that we can go on with the major job.

If one were to try to make predictions, he would probably use about 90 per cent of the automatic flight elements that we have now. If he accepted them and overcame some of these psychological problems, he could do the major portion of this job which involves monitoring. The job that involves completely programed flight, with only minor control direction, is still ahead. Probably it is not so far as one might assume.

Let us go back to this newsman's comment: You want to take off from New York to London. You sit down and calculate all of your data, put it on IBM cards, and then take the cards out and stick them into the machine. Then the crew is in there for what? To take care of those unforeseen conditions that you can't provide for in advance. Automatic flight is limited, and only the human element can provide an infinite number of parameters to that particular operation at any specific moment. There is always that element where judgment comes in.

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Electronics

Adaptability to Aircraft Engine Control

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Eclipse-Pioneer Division, Bendix Aviation Corporation

ABSTRACT

A means of simplifying the ever more complicated task of efficiently operating an aircraft power plant is presented. Although originally developed for use in a "single-lever" engine-control system, this method utilizes electronic and servo principles that can be adapted to a variety of engine controls for use in single- or multiengined aircraft. The technique, which eliminates the need for a complicated cable and pulley system, is described in detail and its flexibility is demonstrated.

INTRODUCTION

BECAUSE IN MANY CASES the modern aircraft engine is not located in proximity to the cockpit and because most power-plant controls are engine-mounted, the problem of remotely positioning the various specialized controls has become increasingly difficult. At present, the commonly accepted solution is a complicated network of cables and pulleys running between the cockpit and the engine nacelle. In the case of some single-engined aircraft, this method is relatively simple, dependable, and inexpensive. However, in the case of the larger multiengined craft, the adjectives "simple" and "inexpensive" no longer apply, and in some cases severe flexing of the wings and extreme changes of temperature render such a system undependable.

There also remains the problem of automatically coordinating control action in such a manner that maximum performance will be achieved without sacrificing engine life. At present this task is performed manually by members of the flight crew. Constantly changing flight conditions, however, render the process of determining and maintaining proper control settings a cumbersome one. The problem is further complicated on a multiengined ship by the necessity for synchronizing the power output of the individual engines.

As an answer to this problem, the Eclipse-Pioneer Division of Bendix Aviation Corporation has developed and flight-tested a single-lever power-control system that incorporates a method of coordinating the action of several engine controls through the use of servomechanisms. This eliminates the need for a complicated cable and pulley system with its associated difficulties and, at the same time, relieves the flight crew of the task of control coordination.

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GENERAL

The technique to be discussed is based on a simple, remote torque-control system that provides an electrical means of causing the input lever or shaft on an engine-mounted control mechanism to follow the motion of a cockpit control lever. The basic system, which operates from a single-phase, 115-volt, 400-cycle source, consists of four units—an amplifier, two synchros, and a servomotor.

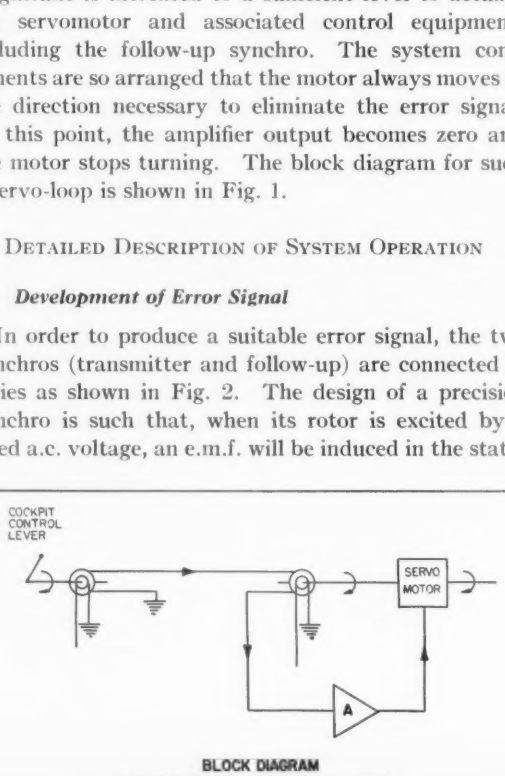
The rotor of one synchro (known as the transmitter) is mechanically linked to a cockpit control lever, while the rotor of the other is coupled to the input arm on an engine-mounted control. The equipment is electrically connected in such a manner that it produces an error signal that is at all times proportional to the angular misalignment between the cockpit control lever and the input arm on the engine-mounted control mechanism.

The error signal is then fed into the amplifier where its magnitude is increased to a sufficient level to actuate the servomotor and associated control equipment, including the follow-up synchro. The system components are so arranged that the motor always moves in the direction necessary to eliminate the error signal. At this point, the amplifier output becomes zero and the motor stops turning. The block diagram for such a servo-loop is shown in Fig. 1.

DETAILED DESCRIPTION OF SYSTEM OPERATION

(I) *Development of Error Signal*

In order to produce a suitable error signal, the two synchros (transmitter and follow-up) are connected in series as shown in Fig. 2. The design of a precision synchro is such that, when its rotor is excited by a fixed a.c. voltage, an e.m.f. will be induced in the stator



BLOCK DIAGRAM
REMOTE TORQUE CONTROL SYSTEM
(FIGURE 1)

which is proportional to the angular position of the rotor. (See Fig. 3.) Therefore, with the rotor of the transmitter synchro linked to the pilot's control lever and the rotor of the follow-up synchro coupled to the input arm on an engine-mounted control, two voltage signals will be developed, each sensitive to the position of its associated equipment.

In order to obtain a usable error signal, it is necessary to arrange the two synchros in such a manner that the voltages across the stators be in phase opposition and be equal in magnitude when the cockpit control lever is properly aligned with the input arm on the equipment to be controlled. It is also necessary to design the two rotor drives so that full angular travel of the transmitter rotor is equal to the full angular travel of the follow-up rotor.

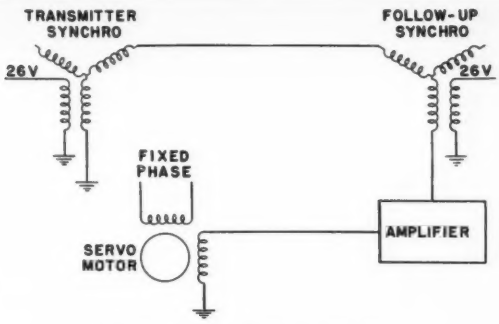
This arrangement produces an error signal that is at all times proportional to any misalignment between the cockpit control lever and the input arm on the engine-mounted control. That is, if both pieces of equipment are properly aligned, their respective synchros will put out voltages of equal magnitude but opposite phase, which when summed in the series circuit (Fig. 2) will yield a zero error signal. However, if the two pieces of equipment are not aligned, one synchro voltage will be greater than the other causing the circuit to produce an error signal equal to the difference in stator voltages. The greater the amount of mechanical misalignment, the stronger the error signal. Whether the signal is positive or negative will be determined by the phase relationship of the transmitter output to that of the follow-up.

In order to eliminate any possible ambiguity in the system, the synchro shafts are linked to the cockpit control lever and the engine-mounted control in such a manner that full angular travel of the rotors is no greater than 90°. The 90° of travel should be selected to coincide with the straight line portion of the synchro output voltage curve (see Fig. 3).

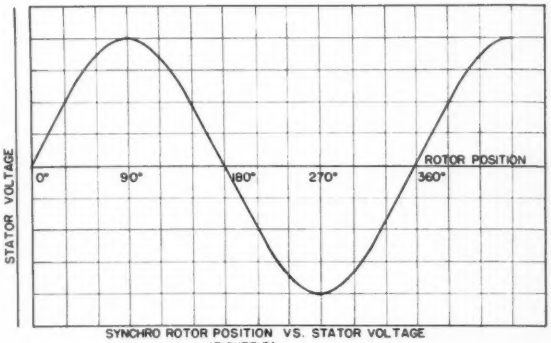
(II) *Servomotor*

The servomotor, which is located adjacent to the engine-mounted control mechanism in question, is the muscle of the servo-loop (Fig. 4). It consists of a two-phase, low-inertia, induction motor coupled through a suitable gear train to an output shaft. Both the motor and the gear train are chosen in accordance with the torque-speed requirements of the mechanism to be controlled.

The fixed-phase of the motor receives continuous a.c. excitation of constant potential. The variable phase receives its excitation from the output stage of the amplifier. Motor torque and speed are controlled by changing the variable-phase excitation. The direction of rotation is governed by the relative phase angle between the fixed- and variable-phase excitation. A rate generator, whose operation will be explained later, is usually mounted on the back of the motor with its armature coupled to the motor shaft.



REMOTE TORQUE CONTROL SYSTEM
(FIGURE 2)



SYNCHRO ROTOR POSITION VS. STATOR VOLTAGE
(FIGURE 3)

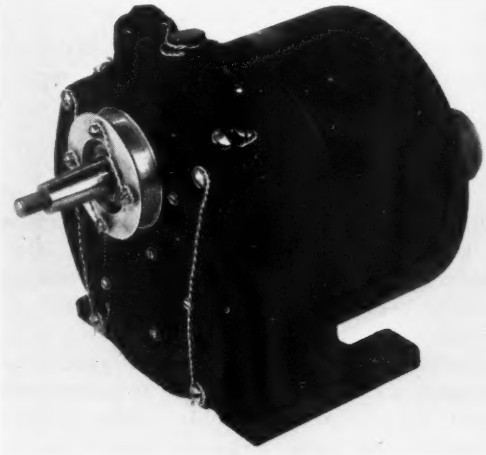
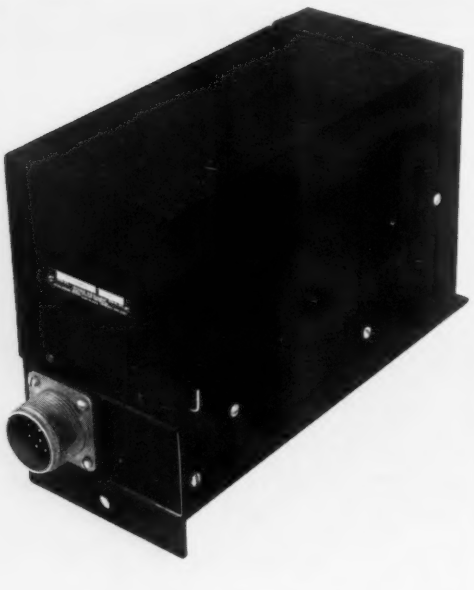


Figure 4

SERVO MOTOR
(Bendix Type XD-707324)

Fixed Phase ----- 115 volts, 400 cycles per sec.
Stall Torque ----- 140 Inch Pounds
Speed ----- 8 RPM No Load
Speed ----- 5 RPM, 100 Inch Pound Load
Weight ---- 5 lbs.



(FIGURE 5)
SERVO AMPLIFIER
BENDIX TYPE 707326-1
WEIGHT-5.25 IBS.

The phase relationship of the error signal, the output of the amplifier, and fixed phase of the servomotor is such that the motor will drive in the direction necessary to eliminate the signal causing the motion. The motor will continue to turn until the rotor of the follow-up synchro, which is coupled to the motor, comes into alignment with the rotor of the transmitter synchro. At this time the cockpit control lever and the input arm on the engine-mounted control will be properly aligned.

(*III*) *Stabilization*

It has been found effective to employ viscous damping by electrical feedback to ensure stable operation of the torque-control system—that is, to feed into the amplifier, in series with the error signal, a rate signal that is proportional to the rotational velocity of the servomotor.

In order to accomplish this, a rate generator, whose armature is mounted on the same shaft as the motor, is added to the servomotor assembly. Thus, the generator turns with the motor. The rate signal is opposite in polarity to the error signal and of small enough magnitude that it becomes of importance only when the error signal is small—i.e., when the follow-up synchro nears the desired position. At that point, the error signal is approaching zero but the motor is still turning at high speed. When the error signal becomes less than the rate signal, the polarity of the total signal delivered to the amplifier is reversed and the corresponding excitation supplied to the variable phase of the induction motor is also reversed. This process creates a motor torque opposite to the direction of rotation, which produces a braking action on the motor. As the motor speed decreases, the rate signal also diminishes. System parameters are so arranged that, as the error signal, rate signal, and motor speed all approach zero, the servo output shaft will come to the desired position without overshooting.

(*IV*) *Amplifier*

Since the magnitude of the error and rate signals is not large enough to control accurately the action of a motor directly, it is necessary to add an amplifier to the system. The amplifier must be capable of increasing the size of the control signal to a value sufficient to energize the variable phase of the servomotor. It is also necessary that it be phase sensitive. An amplifier that meets these requirements has been designed and used successfully as part of the Bendix Single Lever Power Control Syatem (Fig. 5). The circuit includes two dual triodes, one used as a combination rectifier and signal amplifier and the other as a grid-controlled synchronous rectifier. A magnetic amplifier is employed for the output stage.

A simplified explanation of the amplifier's operation is as follows: The input or control signal (rate plus error) is applied to the grid of one of the dual triodes, where it is amplified approximately 500 times. The amplified signal is then applied to the control grids of the other dual triode. This tube, acting as a grid-controlled synchronous rectifier, acts to regulate the saturating currents in the magnetic amplifier.

(*V*) *Application for Basic Torque-Control System*

The system just described has been found flexible enough to lend itself to a variety of engine-control applications and is especially advantageous in installations where the operator's station is not located in proximity to the engine itself. The method outlined has been used successfully on several multiengined aircraft to remotely control the position of such things as cooling flaps, carburetor mixture controls, throttle butterfly valves, and propeller governor or synchronizer settings.

Utilization of this equipment makes it possible to eliminate the complicated cable and pulley systems that are used on most present-day aircraft. Although cable controls have been satisfactory in the past, most aircraft system designers have found it increasingly difficult to allocate sufficient space in the wings of today's long-range multiengined airplane for the extensive network of pulleys and cables necessary to control all the engines. The present trend toward manual control for the leaning of carburetors, to obtain maximum range operation, has made it necessary for the flight engineer to make and maintain small adjustments to the setting of the carburetor mixture control. This regulation process is almost impossible to accomplish with a mechanical positioning system. It has been found that such things as wing flexing and severe temperature changes impair the efficiency of mechanical positioning equipment. These conditions do not affect the performance of an electric system.

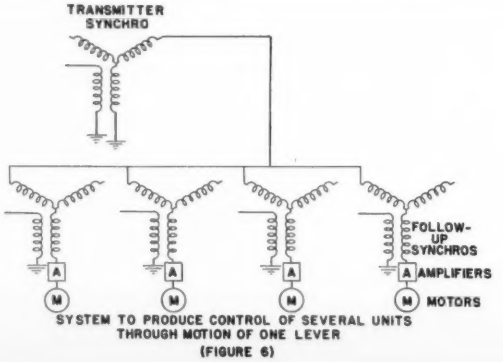
(VI) *Coordination of Control Systems*

The operation of multiengined aircraft is such that it is often necessary to actuate simultaneously several controls in parallel. Such a condition is evident during take-off and landings when operating conditions are changing rapidly. For example, during take-off the pilot of a multiengined plane must advance from four to six throttle levers with one hand and control the attitude of the ship with the other. Then, immediately after becoming air-borne, he must retard power and start to climb.

When electric torque-control equipment has been installed on an airplane, it is a simple matter to regulate the action of several controls through the motion of one lever. By wiring four follow-up synchros in parallel and connecting the group in series with a transmitter as shown in Fig. 6, it is possible to produce four error signals, each dependent on the angular misalignment between the single transmitter rotor and the individual follow-up rotors. This scheme allows the pilot to position all throttles simultaneously by moving a single control lever. A switching arrangement can be designed that will make it possible for the pilot to control the throttles individually or in a group at his discretion.

In order to obtain maximum performance from a reciprocating engine, it is necessary to schedule engine manifold pressure and r.p.m. as determined by the engine manufacturer. The standard method of maintaining such a schedule is to first set the propeller governor to maintain a required engine speed and then set the manifold pressure control mechanism to yield the necessary pressure. Since these manual operations are often extremely inconvenient, it has long been the desire of engineers associated with aircraft engine controls to relieve the pilot of this responsibility. Remote torque-control equipment can be easily adapted to a system for automatically scheduling the action of two or more engine controls.

Since many propeller governors and synchronizers control engine speed as a function of input-arm position, it is possible to establish a schedule of transmitter rotor position vs. engine r.p.m. (Fig. 7). There are also controls on the market which regulate manifold pressure as a function of pilot's throttle-lever position.



SYSTEM TO PRODUCE CONTROL OF SEVERAL UNITS THROUGH MOTION OF ONE LEVER
(FIGURE 6)

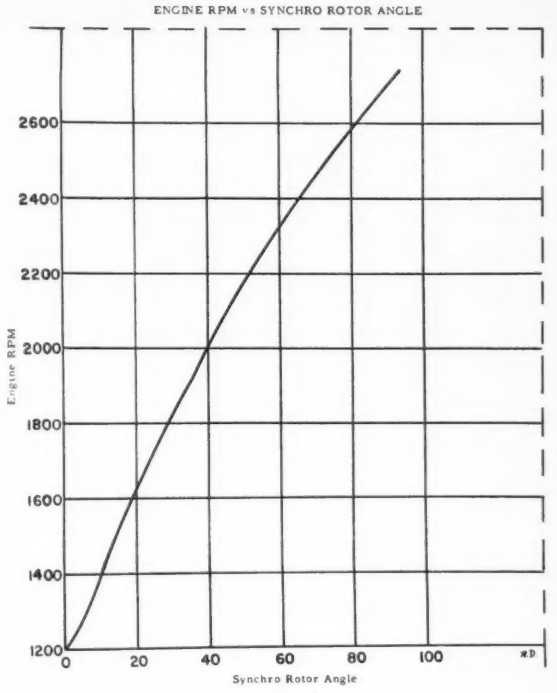


Figure 7

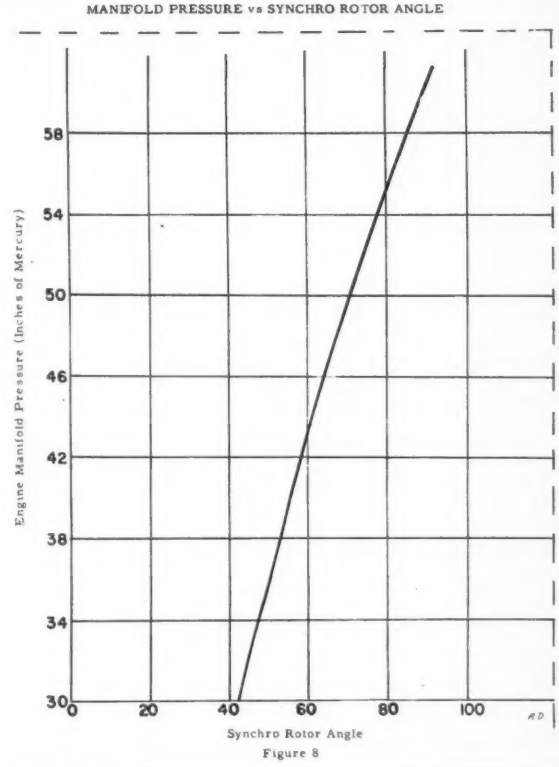
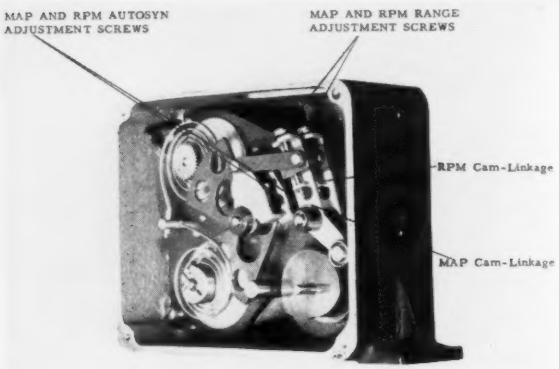


Figure 8

Therefore, the procedure outlined above can again be followed to obtain a schedule of synchro rotor position vs. engine manifold pressure (Fig. 8). Once the two schedules have been determined, it is a relatively



(FIGURE 9)
POWER TRANSMITTER
WEIGHT — 2 IBS.

simple matter to design a system of cams and follower-arms to position the two synchro transmitter rotors in such a manner that, as each value of engine r.p.m. is selected, there will be a corresponding value of manifold pressure automatically selected at the same time. In the case of Bendix Single Lever Power Control equipment, the r.p.m. and manifold pressure cams, the two transmitter synchros, and the cam followers are incorporated in an assembly referred to as a Power Transmitter (Fig. 9).

By mechanically linking the cam shaft to a control lever, it is possible to give the pilot automatically scheduled engine control through the motion of one lever.

Equipment of this type has been installed and successfully flight-tested on several multiengined aircraft. Such a control system is extremely effective when used in conjunction with automatic air speed or landing control equipment. A Bendix-built Single Lever Control System is now in use on an air Force B-50 that is employed in all-weather flight-test work.

(*VII*) *Automatic Protection Equipment*

In the interest of safety and efficiency, aircraft engine operating schedules must often be restricted. For example, the manifold pressure-r.p.m. combination called for at sea level is usually not the same as required for altitude operation. It is also true that there is a maximum safe air speed above which an aircraft should not be driven, and once this velocity is attained power should be retarded. Some aircraft engines are equipped with antidetonation equipment that makes it possible to exceed the normally specified operating limits for a short period of time. When this time interval has been exceeded, the power must again be brought within normal limits. Another occasion when a power reduction is necessary is during propeller feathering. At this time it is recommended procedure for the pilot to retard the throttle as soon as he actuates the feathering switch. Obviously, an automatic means of altering throttle settings when any of the above conditions exist would be of considerable assistance to the pilot.

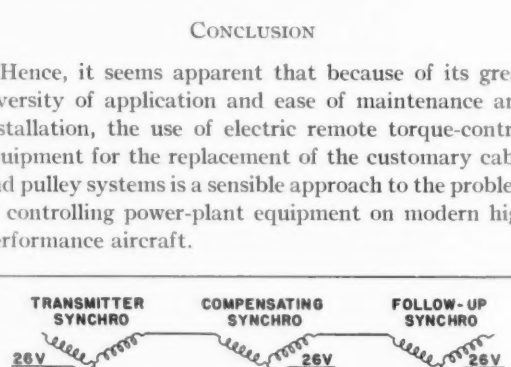
When using an electrical torque-control system of compensation, signals can be added to the basic error signal by including an additional synchro in the original circuit (Fig. 10). This arrangement produces an error signal equal to the sum of the stator voltages from three synchros instead of two as in the original circuit. If the rotor of the third synchro or compensating synchro is so positioned that its stator voltage is zero, it will have no effect and thus add zero compensation to the control system. If, however, the compensating synchro is not nulled, it will add a compensating voltage to the basic error signal. By driving the rotor of the compensating synchro with an altitude-sensitive bellows, the signal generated becomes dependent on altitude. When added to the basic error signal, it can be used to compensate a sea-level power schedule for altitude operation. Such an arrangement is used in the Bendix Single Lever Power Control System to obtain altitude-compensated control of a Pratt & Whitney R-4360 engine.

For example, operation of an R-4360 engine below 15,000 ft. at 2,000 r.p.m. calls for a manifold pressure of 39.9 in. Hg. Under this condition, the compensating synchro is nulled and has no effect on the circuit. However, when the plane climbs to a higher altitude, the manifold pressure should be decreased. Under this condition, the compensating synchro develops a signal that will cause the manifold pressure to be reduced to the proper value.

In a similar manner, a signal, sensitive to air speed, can be used to retard power before an excessive air speed is reached. It is also possible to create a signal that will cause the throttle to be retarded whenever the feathering switch is actuated or whenever the supply of antidetonation fluid has been exhausted.

Conclusion

Hence, it seems apparent that because of its great diversity of application and ease of maintenance and installation, the use of electric remote torque-control equipment for the replacement of the customary cable and pulley systems is a sensible approach to the problem of controlling power-plant equipment on modern high performance aircraft.



SCHEMATIC WIRING DIAGRAM
(FIGURE 10)

Aircraft Omnidirectional Antenna Problem for U.H.F. Navigation Systems*

A. G. KANDOIAN

Federal Telecommunication Laboratories

Introduction

As radio aids to aerial navigation, such as Distance Measuring Equipment (DME) and Radar Safety Beacon (RSB) and similar devices, go higher and higher in the radio frequency spectrum (shorter and shorter wave lengths), they give rise to two fundamental problems associated with the antenna and radiation characteristics required by these radio aids. These problems must be appreciated and properly solved before these U.H.F. navigation systems can be considered completely successful.

Problems

The first problem concerns the effective area of the antenna, which for the desired omnidirectional radiation pattern varies directly as the square of the wave length. This means for the receiving case, with a given power density of the electromagnetic field (in watts per square meter), less energy is picked up by the aircraft antenna at the higher frequencies.

The second problem comes about because the effective area of the airplane surfaces is very large compared to the very small area of the antenna. There is no practical location available on the aircraft which is in optical sight of all directions with which communication must be maintained. The situation is, of course, further complicated during aircraft maneuver when large aircraft surfaces may further obstruct the line of sight. Where to locate the antenna so that its normally satisfactory radiation pattern will not be badly distorted by the aircraft surfaces is finally the problem that faces the aircraft antenna engineer.

The question of how to design the antenna to be aerodynamically acceptable for these applications at U.H.F. is a relatively minor one because, the physical size of the antenna being small, it lends itself without too much complication to a design flush with the aircraft surfaces.

The first of these problems has no direct solution from the antenna standpoint. The present state of the art does not permit, in a practical form, a larger antenna area (in terms of wave length) without at the same time increasing directivity, which is not acceptable in this application. This problem must therefore be solved by using more transmitter power than would be necessary at lower frequencies.

A solution to the second problem (providing satisfactory coverage at U.H.F.) is more complex than has been appreciated in general. In fact as recently as a year ago, long after the various navigation systems in question had been assigned to the U.H.F. bands, the most authoritative view[1] was that "solution of the ultra-high-frequency problem is not yet in sight. . . ."

As a result of fundamental studies[2] sponsored by the Air Navigation Development Board, however, some reasonable solutions to this problem are now definitely in sight. The following gives the basis for the above view.

Analysis and Measurements

At the ultra high frequencies, the aerodynamic problem presented by any antenna likely to be used for these applications is relatively minor. Dipoles are small, and flush cavity antennas are quite practical. However, as previously pointed out, the effective areas of these antennas are small, and the airplane body seriously interferes with the nondirectional properties of the effective dipole by (a) shadowing, due to aircraft

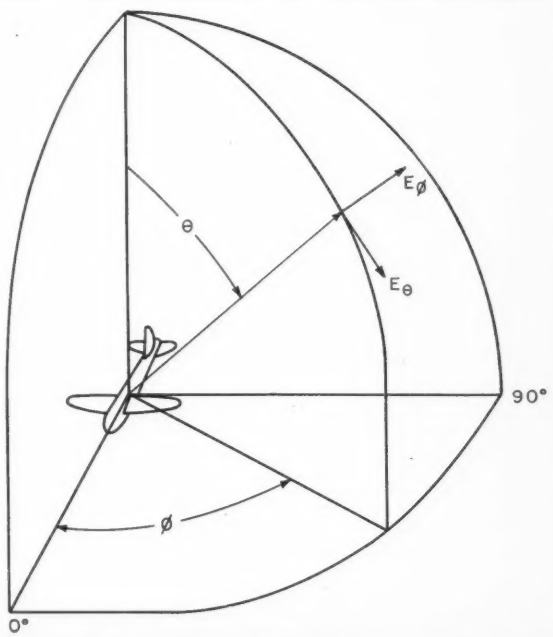


Fig. 1. Geometry of model measurements.

Presented at the Electronics Session, Twenty-First Annual Meeting, I.A.S., New York, January 25–29, 1953.

* Most of the work reported here has been carried on by Messrs. W. Sichak and J. J. Nail,[2] of the Federal Telecommunication Laboratories. Helpful conferences on the subject have been held with H. Senf, of A.N.D.B., W. Pike, of BuAer, and Dr. L. J. Chu, of M.I.T.

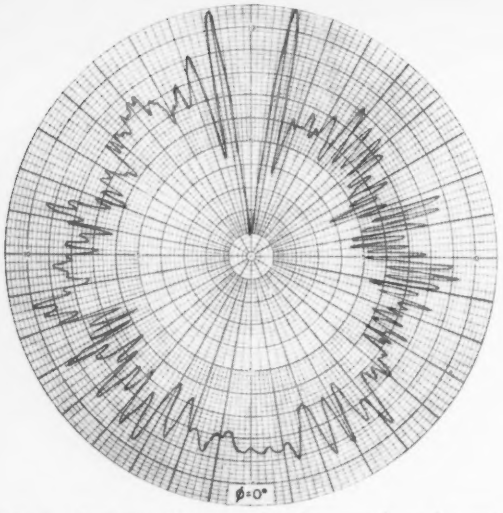


FIG. 2. Typical 1,000-mc. azimuth power intensity pattern of vertical λ/4 stub antenna mounted at the top of the fuselage of a DC-3 aircraft.

wing or tail getting in the line of radiation, and (b) reradiation, causing wave interference with resulting rapid fluctuation of the radiation pattern of the antenna.

The above analysis is illustrated by scale-model measurements where the purpose is to see what typical radiation patterns can be achieved by locating the vertical dipole antenna at likely positions on aircraft of various types. Fig. 1 illustrates the geometry of model measurements where θ is the angle of elevation which is zero straight up, and ϕ is azimuth angle with zero forward.

Fig. 2 shows the azimuth radiation pattern for the antenna located at the top of the fuselage on the centerline of the wings. The airplane type is DC-3. It can be seen that in the horizontal plane a considerable defect in the pattern is due to shadowing of the radiation due to the tail structure. Little radiation results in the rear 20 deg. In other azimuth directions, it is evident there is a great deal of signal fluctuation due to reradiation from the various surfaces.

However, the chief defect is not in the azimuth pattern ($\theta = 90$), but rather in the rapid decrease in signal level at vertical angles below the horizon. This is illustrated in Fig. 3, where complete radiation patterns are shown at various elevation angles within 25° above and below horizontal. It is evident that, at 5° to 25° below horizon ($\theta = 95$–115), the antenna radiation is greatly reduced, and hence, the results are totally unacceptable for the systems we are considering. Above the horizon, as might be expected for this location of the antenna, the radiation is relatively favorable.

Though these results and other data to follow have been taken on DC-3 aircraft, the results are typical and, in a general way, apply to all metallic aircraft of this size or larger. The only noteworthy difference will be that, for larger aircraft, the shadow areas are more pronounced and the signal fluctuation in other directions due to wave interference will be more rapid, though not necessarily more severe, with change of angle.

A further factor to be emphasized is that the general characteristics apply for other polarizations and types of radiators than the vertical quarter-wave stub used in most of these experiments. It should therefore not be considered that with a clever design of the antenna or proper choice of polarization the overall radiation characteristics will be substantially improved.

The net conclusion is, therefore, *a U.H.F. omnidirectional antenna located above the fuselage cannot give adequate coverage even slightly below the plane of the wings (horizon).*

Fig. 4 shows a typical azimuth pattern for a belly location of the antenna. As can be seen, there are no deep shadow areas. However, there are rapid fluctuations in pattern due to reradiation from various surfaces of the aircraft. The major defect in this case, however, is that the antenna pickup drops drastically at vertical angles *above the horizon.* Hence, the conclusion is that *for belly location of a U.H.F. antenna adequate coverage cannot be achieved for vertical angles above the plane of the wings (horizon).*

Fig. 5 shows a typical azimuth pattern for the antenna located at the nose of the airplane. The coverage in the forward sector is now satisfactory, as is the variation with angle of elevation, but there is no coverage back toward the tail. Similarly, Fig. 6 shows excellent coverage in the rear directions for antenna located at the tail, but such a location cannot provide adequate forward coverage. Corresponding conclusions may be drawn for wing-tip location of U.H.F. antenna as illustrated by Fig. 7.

Because of space and time limitations, it does not appear justified to cite more detailed data than here presented. The conclusion, however, appears inescapable—namely, *for large metallic aircraft (DC-3 or larger), it is not possible to find a single practical antenna location to give adequate coverage for U.H.F. omnidirectional navigation systems.* In fact, no single location can even come close to meeting this requirement, where adequate coverage is generally taken to mean all azimuth angles and plus or minus 30° in elevation.

The next reasonable approach then is to consider more than one antenna location—complementary locations—for either simultaneous or on an "either-or" radiation basis. From previous data, it is evident that a good pair of antennas for complementary coverage can be obtained by pairing (a) top and belly antennas, (b) two wing-tip antennas, and (c) nose and tail antennas.

A brief consideration will show that of these the preferable combination is the nose and tail antenna system if the two antennas are to radiate simultaneously (the simplest system). If the antenna is to be an "either-or" type (one antenna radiating at a time), then it may be preferable to use the top and belly antenna locations. In the latter case, a switch or its equivalent is necessary between the two antennas.

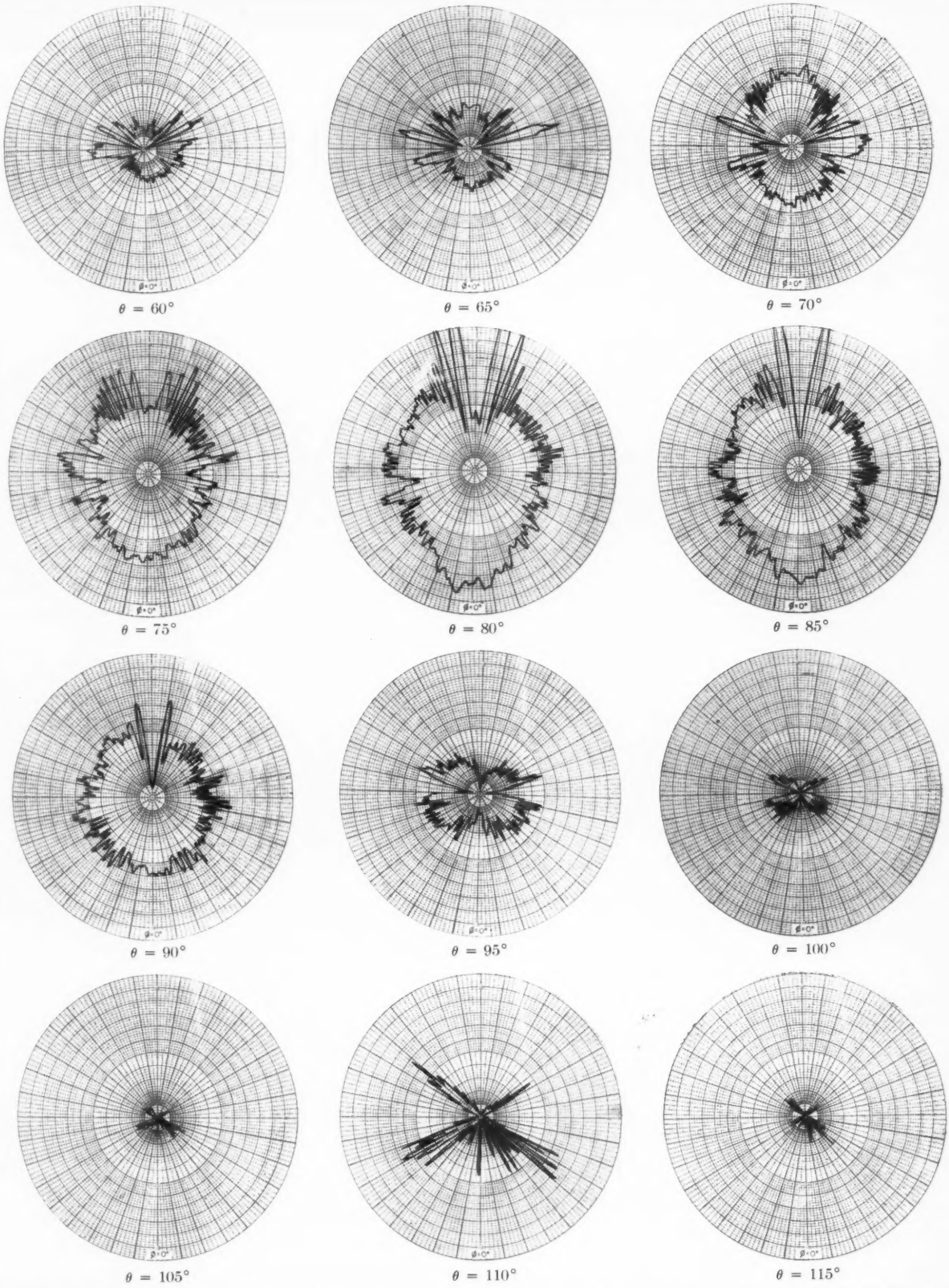


FIG. 3. Typical 1,000-mc. azimuth power intensity pattern as in Fig. 2 shown at various vertical angles θ above and below horizontal (at which $\theta = 90°$).

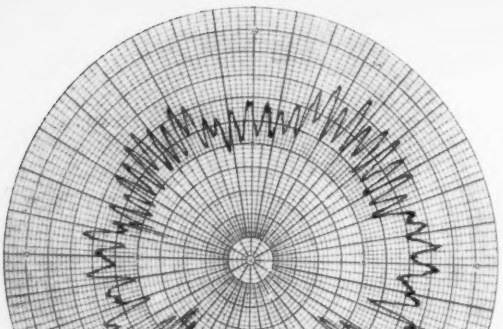


FIG. 4. Typical 1,000-mc. azimuth field intensity pattern of vertical stub antenna mounted on the belly of a DC-3 aircraft.

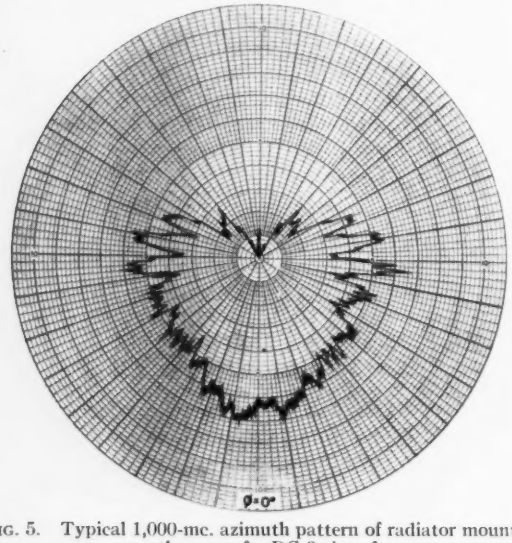


FIG. 5. Typical 1,000-mc. azimuth pattern of radiator mounted on the nose of a DC-3 aircraft.

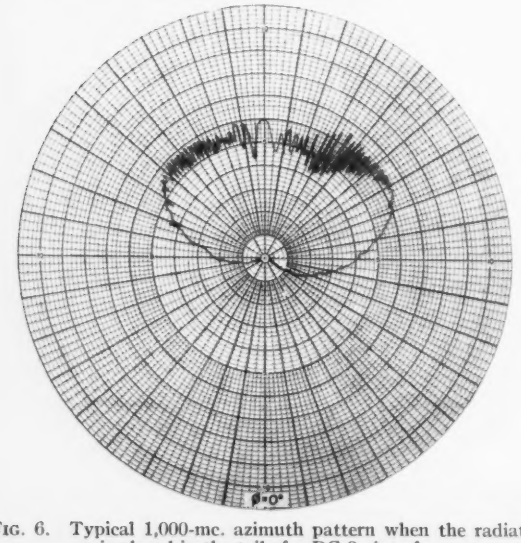


FIG. 6. Typical 1,000-mc. azimuth pattern when the radiator is placed in the tail of a DC-3 aircraft.

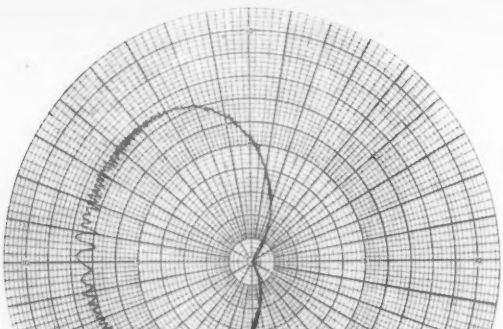


FIG. 7. Typical 1,000-mc. azimuth pattern when the radiator is mounted on one of the wing tips.

Simultaneous operation of nose and tail antennas simply tied together gives coverage, as illustrated in Fig. 8. This is not an optimized design and is intended merely to illustrate the system. It is seen that in the forward direction the forward antenna predominates, giving excellent coverage. In the rear direction, the tail antenna predominates, and, again, good coverage is achieved.

It is to be noted that in the particular case illustrated some gain was given to the forward antenna, which may or may not be desirable. The wing-tip directions represent common radiation regions for both the nose and tail antennas, and, hence, violent fluctuation of signals results because of constructive and destructive interference. The average radiation is good even in this "vulnerable" region. For larger aircraft or at higher frequencies, the fluctuations would tend to be more rapid with angle. Since these fluctuations are not desirable, by using the combination of the nose and tail antennas, they are confined to wing-tip directions considered to be the least vulnerable directions from the navigation standpoint. With an optimized design, this fluctuating signal region can be more limited than here illustrated. It can also be oriented in different directions from the ones shown. It is to be noted, however, with this paired antenna there is little variation of the coverage pattern with vertical angle θ. The coverage remains virtually the same for $\pm 15°$ in elevation as illustrated and beyond.

Should the overlapping region signal fluctuations be intolerable in any application, it is possible to introduce either a phase changer or a switch in the arm of one of the two antennas, and the relative phase of one of the pair may be reversed at any desired rate (the changeover itself to occur as fast as possible). This will convert any minimum signal direction off wing tips to a maximum at the chosen switching rate. In the forward or backward direction, there will be no noticeable change in level.

Combining either the top and bottom antennas or the two wing-tip antennas to make up a simultaneously radiating complementary pair of antennas is less desirable than the combination of nose and tail antennas previously discussed. The reason is that the "vulnerable" region caused by the overlapping complementary radiation patterns would be in more important directions, all azimuth directions in the former case and in the fore-and-aft directions in the case of the paired wing-tip antennas.

In the event that the particular navigation system in question (such as DME) can tolerate an "either-or" antenna system to get omnidirectional coverage, it may be preferable to use the top and bottom antennas, one or the other of which could be connected to the equipment at one time. When satisfactory response is not achieved from the antenna connected, the switch turns to the other antenna. The reason for preferring the top and bottom antennas under these conditions is that the longer cable lengths necessary to reach the nose and tail antennas (and corresponding radio frequency losses) may then be avoided.

Advantages of Multiple Antenna System

Though it is obviously undesirable to use two or more antennas where one can do the job, in this case since complementary antennas are necessary, we may derive certain other advantages from their use. One is that each antenna now has the aircraft behind it and radiates a predictable clear pattern and, hence, gives rise to little difficulty due to reradiation from parts of the airplane. A second advantage is that a certain amount of vertical pattern gain may be practical, since at most a $\pm 30°$ coverage is required in the vertical plane. Since the wave lengths at U.H.F. are small, a 3–5-db. vertical gain appears to be not unreasonable.

The most important advantage, however, is that a potent multiplexing tool becomes available since two independent antenna loads are available. This is illustrated in Fig. 9. By the use of a radio frequency bridge (similar to the hybrid circuit in audio work), two equipments may be diplexed on the two antennas and still achieve the advantage of the overlapping complementary radiation patterns. With a properly balanced radio frequency bridge, an isolation of the order of 30 db. can be achieved even if both equipments operate at the same frequency and, correspondingly more, if the frequencies of the two equipments are not identical.

Measuring Technique

The measured data reported here have been taken at 24,000 mc. with scale models of various types of aircraft. The scaling factors were chosen to correspond to actual frequencies of 1,000–3,000 mc. The airplane with antenna system under test was used as a receiving system. The transmitter was located sufficiently far away to ensure a uniform field at the receiving location.

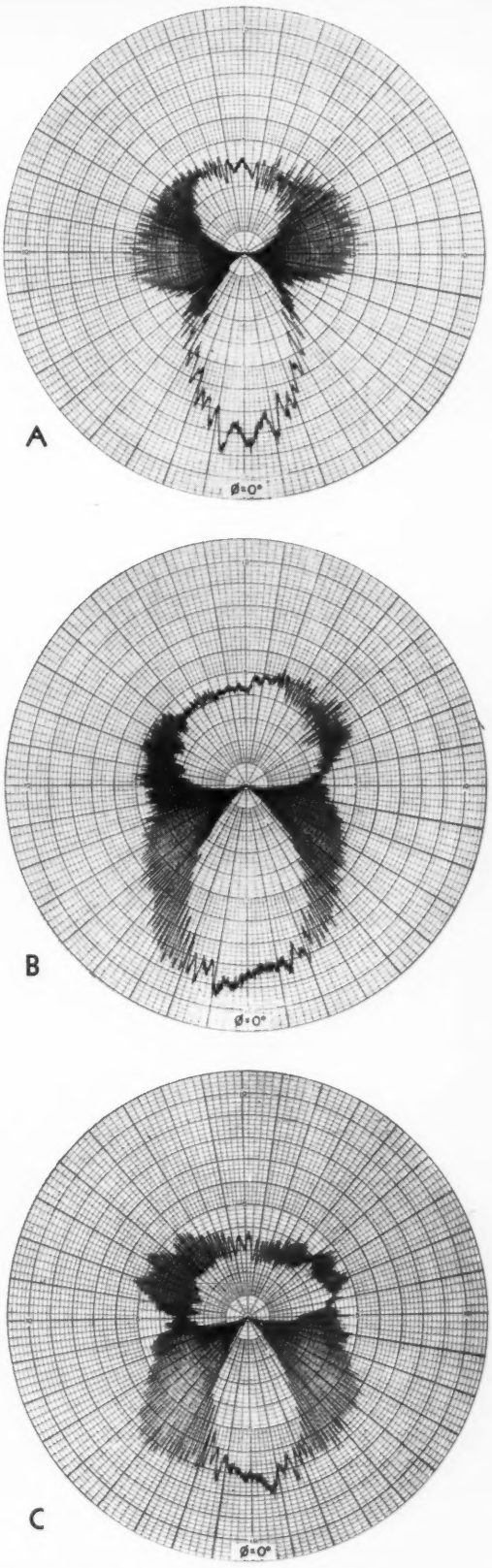


Fig. 8. Typical azimuth field intensity patterns when two widely separated radiators are used, one nose and one tail, at three vertical angles $\theta = 105°$ (A), 90° (B), and 75° (C). Note the relatively little change in pattern with vertical angle.

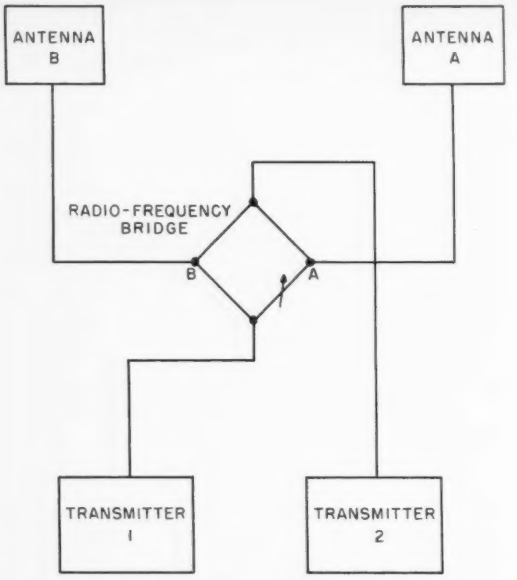


FIG. 9. A method of operating two equipments on a dual complementary parallel antenna system.

FIG. 10. Model of DC-3 aircraft mounted for measurements. The angular deflection plate below the antenna shields the tilting mechanism to prevent coupling to the test antenna on the aircraft.

Figs. 10 and 11 show models of DC-3 and DC-6 used in actual measurements. The modeling technique and compilation and analysis of data are discussed elsewhere.[1]

CONCLUSION

It appears that there is a good possibility of a solution to the aircraft antenna problem both for Distance Measuring Equipment and Radar Safety Beacon by using a single pair of antennas simultaneously. In any case, it seems quite certain that a separate solution, each involving a pair of antennas, is feasible both for DME and RSB.

The above conclusions are based on sound engineering considerations and scale-model experimental data. But these are no substitute for final test of actual antennas with working DME and RSB equipments installed in an aircraft (preferably several types of aircraft). There remains the considerable amount of work in the actual design of suitable full-scale antennas to test properly the several promising combinations of pairs of antennas with working equipments. This is necessary in order to be sure that no unforeseen limitations or practical considerations stand in the way of a satisfactory solution to the problem of aircraft antenna for U.H.F. Navigation Systems.

It is expected that this part of the work will be well under way in the near future.

REFERENCES

[1] Granger, J. V. N., *Design Limitations on Aircraft Antenna Systems*, Aeronautical Engineering Review, Vol. 11, No. 5, p. 82, May, 1952.

[2] Sichak, W., and Nail, J. J., *UHF Omnidirectional Antenna Systems for Large Aircraft*, submitted to Proceedings of I.R.E. for publication.

FIG. 11. Model of DC-6 aircraft showing more details of mount and tilt mechanism.

Systematic Cooling of Air-Borne Electronic Equipment*

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SUMMARY

For systematic cooling, electronic units should have coolant flow connections and defined thermal characteristics which correlate surface temperature rise of basic components with coolant flow rate. For least penalty on aircraft flight performance, cooling systems should function with minimum internal temperature gradient. If permissible, flow of the ultimate coolant over electronic component surfaces is thermally most advantageous. In central and group cooling systems, it is desirable to employ one or more transfer fluids, with or without refrigeration. When designing units for least internal temperature gradient, methods to be considered for cooling of component surfaces are: forced air or liquid flow, natural liquid convection or liquid spray (with or without boiling), and conduction to external cooling surfaces. The physical characteristics and cooling power requirements of units having the same electrical performance, but different configurations suitable for application of these methods, are compared on the basis of experimental and analytical data. Vertical-flow forced-air cooling of open units and internal liquid-spray cooling of closed units result in best thermal performance for each type.

INTRODUCTION

ELECTRONIC SYSTEMS needed to accomplish the various missions of modern aircraft have been composites of equipment units of many different physical configurations. These have evolved in meeting requirements of electrical functioning and heat dissipation at high altitude. For example, high voltage has made pressurization or sealing necessary. To this type of construction, the cylindrical equipment case has been most readily adaptable. It has been accepted for its simplicity and small weight, while the waste of installation space it produces has often been overlooked. Whether sealed or open to the atmosphere, units of widely different volumetric heat concentrations have frequently resulted either from specifications of dimensional limits chosen without consideration of probable heat generation or from restrictions imposed by mechanical and dimensional characteristics of basic electronic components, irrespective of heat generation rate. Cooling methods have been used to cope as simply as possible with the encountered heat concentrations. Up to 200 watts per cu. ft. natural external and/or internal cooling has often been adequate. For greater heat concentrations forced airflow has been used, either over component or case surfaces (up to 500 watts per cu.ft.) or through passages of internal, envelope-type, and separate heat exchangers (up to 1,000 watts per cu.ft.).

Based on environmental specifications that have evolved from concepts of thermal rating electrical machinery designed for stationary application, electronic units are being developed which utilize individually the atmosphere of the installation compartment as heat sink. Their thermal evaluation is frequently performed under the unrealistic environmental conditions produced in an altitude chamber having high internal air velocities and containing no other electronic gear in the proximity of the test unit. When installed in an aircraft, the unit would require at the same air pressure a lower compartment air temperature if confined closely by other heat-dissipating equipment and if not exposed to high-velocity air motion as in the altitude chamber. Airframe manufacturers' personnel has been charged with the responsibility to provide suitable thermal conditions, usually without being furnished rational thermal data for the equipment. Recently, comprehensive methods for the experimental and analytical thermal evaluation of air-cooled electronic equipment have been proposed.[1] The substitution of bench tests and analytical procedures are suggested for many altitude chamber tests currently used. Methods for the presentation of equipment thermal characteristics in generalized form (fundamentally based on limiting component surface temperatures) are recommended, which should aid in the adaption of most types of units to a considerable range of aircraft installation compartment conditions.

EQUIPMENT COOLING SYSTEMS

Frequently, equipment designed for heat dissipation to the compartment atmosphere and developed for increased output and reduced size is being installed in congested locations within aircraft. This has created a tendency for cooling of equipment compartments

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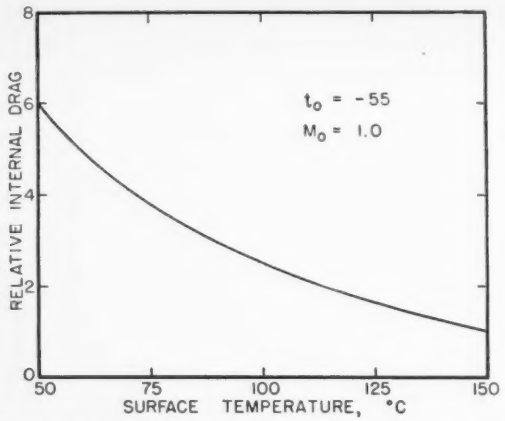


FIG. 1. Effect of heat-transfer surface temperature on internal drag of ram-air cooling system (M_0 = flight Mach Number, t_0 = atmospheric temperature, °C.)

by air refrigeration, using the techniques of cabin comfortization. The combination of cabin and equipment cooling systems is often proposed. Yet, the two cooling problems are of quite different nature. The cabin must be cooled mainly because of external heat gain. Electronic equipment must be cooled to dissipate heat generated internally. Thus, a cooling requirement exists whenever the electronic equipment is operating, while the cabin must be cooled only under certain aircraft operating conditions. For example, in flight at altitudes above 50,000 ft., cooling of the cabin may not be required even over a limited range of supersonic speeds. In the same aircraft, electronic equipment designed with emphasis on size reduction and thus having high heat concentration would be in need of some heat-dissipation system. The temperature and pressure limitations of flight personnel and of electronic components differ substantially. Permissible surface temperatures for electronic components of 100° to 300°C. and the ability of some components to operate satisfactorily at very low air pressure cannot be matched by the human body. It is difficult to cool all surfaces of the human body directly to make occupancy of a high-

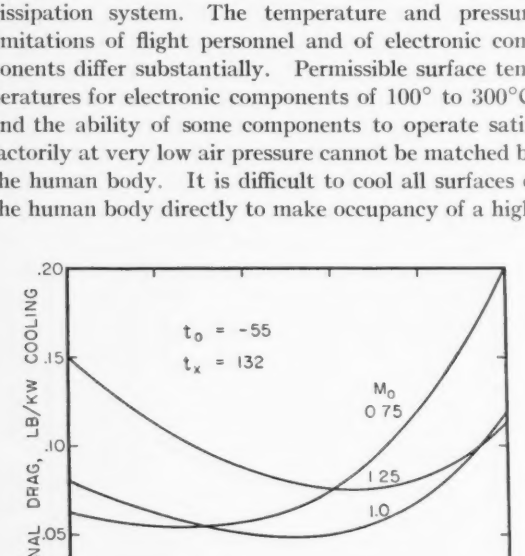


FIG. 2. Effect of heat-exchange effectiveness on internal drag of ram-air cooling system (M_0 = flight Mach Number, t_0 = atmospheric temperature, °C., t_x = heat-exchanger surface temperature, °C.)

temperature environment possible for appreciable time. Therefore, it is necessary to condition the environment. In contrast, direct cooling of electronic equipment, independent of environmental conditions, can be accomplished readily and with greater efficiency than environmental cooling.

Design Considerations

To cool aircraft electronic equipment systematically and without imposing considerable penalty on the flight performance of the aircraft, advantage must be taken of the components' ability to operate at relatively high surface temperature. This can best be done by providing a continuous heat-conveying system from the component surfaces to the ultimate coolant. Such systems should be, as much as possible, isolated from external thermal influences and should have little surface for external heat gain. The conventional aircraft installation compartment does not meet these requirements and is not suitable as an intermediate link in the system. The coolant should be ducted directly to the individual electronic units, should pass through them or over their external heat-exchange surfaces, and should be ducted away. Much equipment currently in use would have to be modified to be made adaptable to this cooling method since each unit would need to have coolant inlet and outlet connections. Most existing units of high heat concentration could be adapted quite readily since they have usually been designed for internal or external forced-air cooling.

Any cooling system imposes by virtue of its weight, space, and power requirements a penalty on the aircraft's flight performance. Thus, its design must represent a compromise, which should be based on careful analysis. In most cases, particularly if the ultimate rejection of heat occurs to air, it is likely that the least performance penalty will be entailed if the temperature of the heat-transfer surface in contact with the ultimate coolant is made to approach component temperatures. This applies to all systems utilizing an ultimate coolant and lower temperature than the components. When the ultimate coolant is at higher temperature and a closed refrigeration system is used as an intermediate thermal link, the latter should receive heat at as high a temperature as practical. The optimum temperature differential to be maintained between component and ultimate heat-transfer surfaces is established when any increase in system weight, space, and power requirements, which may result from a further reduction of the temperature differential, increases the overall penalty imposed on the flight performance of the aircraft.

A typical effect of ultimate heat-transfer surface temperature is illustrated by the variation of internal drag of a simple ram air system[2] for constant cooling capacity, flight speed, and altitude, as shown in Fig. 1. Since the lower drag at higher surface temperature would effect a fuel saving and thus a reduction in aircraft load, a limited increase in weight and power requirements of the electronic equipment and interme-

diate heat-transfer system (if used) to produce higher surface temperature may be desirable, depending on the range and flight speed of the aircraft. Fuel savings at the expense of increased systems weight would be less desirable the shorter the required range. As shown in Fig. 2, the effectiveness of heat exchange—i.e., the extent to which the cooling air temperature is increased and approaches the temperature of the heat-exchange surfaces while passing over them—should be greater at higher flight speed in order to result in least drag.[2] Greater effectiveness can be obtained by arranging the cooling surfaces into passages of greater length.

Higher heat-exchange temperature differentials can be obtained by several means. Obviously, the most direct approach is to raise the allowable surface temperature of all components. Recent component developments have accomplished this successfully. From the standpoint of cooling design, developments of high-temperature components that normally do not generate heat at an appreciable rate, such as capacitors, composition resistors, etc., have been particularly important since they have permitted raising the temperatures of the internal equipment atmosphere to near the permissible surface temperature level of heat-dissipating components which is normally near 200°C. Heat dissipation from the latter can be accomplished with relatively small temperature difference with the aid of high heat-transfer coefficients that may be obtained, for example, with high rates of coolant flow. Thus, high-temperature components facilitate equipment cooling and improve its economy. However, they do not represent in themselves a complete solution to the problem.

With components of given allowable surface temperatures and an available ultimate coolant of given temperature, the highest temperature differentials for heat exchange can be obtained if the ultimate coolant is permitted to contact the surfaces of the component envelopes. Thus, the penalty imposed on aircraft performance by a well-designed open unit in which cooling air originating in the flight atmosphere flows over the tubes, transformers, resistors, etc., is not as great as that of a similar unit using the same components in a sealed case from which heat is being removed through a heat exchanger. The surfaces of the heat exchanger must operate at lower temperature than the components so that a temperature gradient be available for heat flow, regardless of what mechanism of internal heat transfer is being utilized.

If the available ultimate coolant is not suitable as internal equipment atmosphere, the reduction of the temperature gradient between the components and the external cooling surface of the unit to a minimum should generally be the objective. However, this should not be accomplished by a large increase in weight or cooling power requirement of the unit. The permissible increase in complication and weight of the electronic equipment would depend on how critically the ultimate heat-exchange surface temperature affects the weight and power requirements of the entire heat-dissipation system. For example, if low-pressure air of relatively high temperature is the external coolant of a sealed unit, the use of metallic or liquid high-conductance thermal links having appreciable weight would be more justified than if, for example, an expendable evaporative coolant were used for ultimate heat dissipation. Thus, the design of each individual electronic unit is inseparably connected to the characteristics of the entire heat-dissipation system.

Heat Conveyance and Coolants

Cooling systems for electronic equipment operating in the steady thermal state may be broken down into the various parts of the heat-conveying mechanism that, for the individual unit, may function in series. They are (1) ultimate heat dissipation to a coolant that is external to the aircraft or is eventually discharged overboard, (2) intermediate heat dissipation to one or several transfer fluids in series, each circulating in a closed system with or without change of state, and (3) initial heat dissipation from component surfaces to a transfer fluid or an ultimate coolant. Thus, the initial heat dissipation from the component surfaces may also be the ultimate heat dissipation if it takes place to a coolant discharged overboard. In that case no intermiediate coolant would be required. The component coolant may be used as a transfer fluid to a heat-exchange surface from which the ultimate heat dissipation takes place or from which the heat is conveyed by means of another intermediate coolant.

Some possible ultimate coolants may be mentioned: (1) atmospheric air in boundary-layer flow or flowing within the aircraft due to simple ram or blower action; (2) atmospheric air reduced below ram temperature by expansion with energy extraction, with or without previous mechanical compression and cooling; (3) expendable liquids of relatively low vapor pressure having high latent heat of vaporization such as water, methanol, etc.; (4) expendable liquids of relatively high vapor pressure having low heat of vaporization but desirable electrical properties such as Freon refrigerants, etc.; and (5) high-pressure fuel flowing to the aircraft power plant. Ultimate coolants (1), (2), and (4) are potentially also component coolants and can be used for the initial heat dissipation, depending on the electrical requirements of the equipment.

Intermediate coolants may be (1) air at various pressure levels; (2) liquids of good electrical properties such as mineral oil, silicone oil, etc.; (3) liquids having principally good heat-transfer properties but poor electrical properties; (4) liquids that are available on the aircraft such as hydraulic fluids or lube oils; and (5) liquids of relatively high vapor pressure which change their state upon heat addition, are suitable as working fluids in vapor-cycle refrigeration systems, and usually have good electrical properties, such as most modern refrigerants. Intermediate coolants (1), (2), and (5) are potentially also component coolants and can be used within electronic units. In the transfer

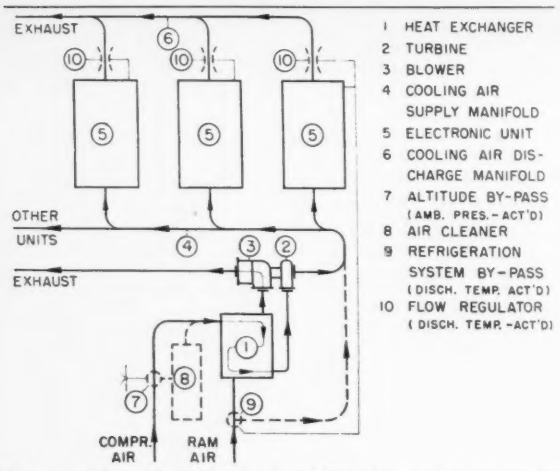


FIG. 3. Schematic of simple air-refrigeration cooling system for electronic equipment group.

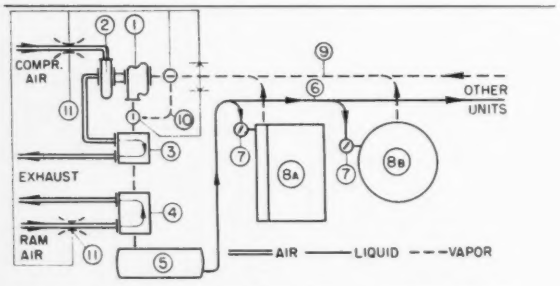


FIG. 4. Schematic of air-driven vapor-cycle refrigeration cooling system for electronic equipment group.

process where mechanical refrigeration may be used to dissipate heat ultimately at a higher temperature than the equipment, the component surfaces proper may serve as the evaporator surfaces in the system.

Most component coolants have been mentioned as ultimate or intermediate coolants. They are (1) air at various pressure levels and (2) liquids of various vapor pressures having suitable electrical properties. Among the liquids, the use of premium-priced fluids may be warranted if they exhibit excellent heat-transfer and electrical properties. Silicone oils are suitable for many applications and are economically acceptable for circulation through units and remote transfer lines of small size. Fluorinated liquids that exhibit excellent electrical and heat-transfer properties are currently high in cost. However, they merit consideration as component coolants to be contained in small quantities within electronic units of high heat concentration.

System Arrangements

The complexity in cooling-system design for electronic equipment increases with the use of transfer fluids different from the ultimate coolant, refrigeration within the transfer system or the ultimate system, number of electronic units to be served by the system, greater distances between units, and different temperature requirements of units within the same system. Many combinations of the basic types of ultimate, intermediate, and component heat-transfer systems are obviously possible. The practicability of each must be defined in terms of the aircraft operating conditions and types of cooling loads for which it is suitable. Under certain conditions, the preferred system may be simple, consisting of an air induction duct with ram-pressure recovery or without pressure recovery but with a blower, furnishing cooling air to one unit of appreciable size and heat dissipation and providing for discharge of the heated air through a duct to the atmosphere. It has the merits of reliability, simplicity, and adaptability to relatively isolated units without the weight penalty of long transfer lines. Even at high flight speeds where the ram air temperature may approach 80°C., such a system may be acceptable, provided that the unit to be cooled is designed for high-velocity forced-air cooling.

Greater complication n the cooling system design and arrangement is warranted when more than one unit is to be cooled. The logical next step in system development is the cooling of a group of units installed in relatively close proximity. For example, the preferred method may be the use of a simple air-refrigeration system installed in or near the equipment compartment, as shown schematically in Fig. 3. This appears desirable when the electronic equipment is located at some distance from the source of compressed air, since it is more economical to convey the cooling air to the equipment's vicinity at high pressure than at the low pressure it reaches after it is precooled by ram air and expanded in the turbine, as shown in Fig. 3. Air refrigeration of this type should find application when the ram-air temperature is higher than the component temperatures or is lower but still so high that, in order to maintain desired equipment temperatures, extremely large quantities of ram air would be necessary and would impose large drag on the aircraft. Such an air-refrigeration system designed for direct equipment cooling could conceivably operate at an optimum turbine exhaust temperature that would be considerably higher than those usually associated with systems of this type used for cabin cooling.

Consideration of vapor-cycle refrigeration would also be warranted when air refrigeration is applicable, particularly should equipments be designed with external or internal liquid-cooling surfaces. The schematic of such a group system is shown in Fig. 4 with a condenser cooled by ram air and a desuperheater cooled by exhaust air from the air turbine driving the refrigerant compressor. The distribution portion of such a system would have the merit of compactness since liquid lines to and return vapor lines from the units would be appreciably smaller than comparable air ducts. The overall penalty of this system on aircraft performance

is likely to be smaller than that of the air refrigeration system shown in Fig. 3. The complexity of control and the requirement for great reliability are increased when a central equipment cooling system is used for the entire aircraft. Such systems may serve other electrical and mechanical equipment components, but their principal heat loads would probably originate with the electronic equipment. Systems of this type would appear warranted mainly to simplify the requirements under conditions where mechanical components must be used (refrigeration systems) or when the ultimate heat dissipation would best occur in a single location. The schematic of Fig. 5 refers to a situation of the latter type. Fuel at high pressure within the power plant's injection system is used as heat sink. Therefore, it is best to bring all heat to be dissipated from equipment items to the power plant. It is also apparent that in a central system the conveying of heat over appreciable distance could be performed more economically in respect to pumping power and space, and probably also in respect to weight, by means of a liquid, as shown in Fig. 5. For best utilization of the liquid intermediate coolant, direct circulation over electronic component surfaces would be thermally desirable but may not be practical from the operational standpoint. Chassis plates with liquid passages represent another possibility. The efficient use of liquid intermediate coolants requires the development of improved equipment design techniques that are especially adapted to this cooling method. Liquid transfer systems can also serve through heat-exchangers groups of air-cooled equipment, as shown in Fig. 5. However, added bulk, weight, and power result from the heat exchangers, closed air-circulation systems, and circulating blowers. In general, the use of liquids as component coolants or intermediate coolants not only makes coolant distribution more economical but also tends to reduce the performance penalties imposed on the aircraft by the ultimate heat-dissipation process since the smallest temperature gradients are required between component and ultimate heat-dissipation surfaces. For large distances, the weight of a liquid distribution system may become so great as to offset the advantages realized by its small pumping power requirement. Its reliability would also be impaired by distance.

The cooling systems discussed above and illustrated in Figs. 3, 4, and 5 are only examples of the many systems that may prove practical, each for a specific range of aircraft operational characteristics. Obviously, there is a tremendous number of possible cooling systems and combinations of ultimate, intermediate, and component coolants, as well as of intermediate refrigeration devices and types of equipment construction. A thorough and complete analysis with an entirely general treatment of all variables is an extremely large task. Therefore, it appears to be most important to collect complete information on the performance and physical characteristics of all potentially applicable parts of possible cooling systems and to develop the methods of systems analysis as best possible.

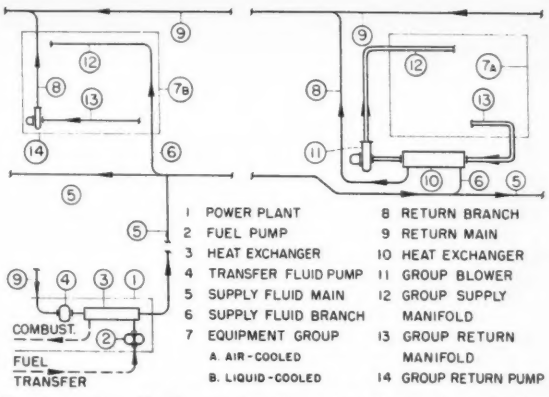


FIG. 5. Schematic of central equipment cooling system with heat rejection to fuel and liquid transfer system.

Then, the choice of the optimum system can be made by conducting the analysis for each specific aircraft based on specified equipment locations, heat-dissipation rates, aircraft operational characteristics, and any restrictive requirements imposed by the mission of the aircraft. This latter task will be the responsibility of airframe manufacturers' personnel. The first task of developing basic data, the methods of analysis, and conducting systems analyses of more general nature which should yield results pointing the direction to be taken in equipment design for systematic cooling are current problems of research.[3]

Equipment Thermal Data for Systems Application

As has been mentioned before, electronic equipment designed for systematic cooling and adaptable to group and central cooling systems in which the compartment atmosphere is not utilized as a heat link must have coolant inlets and outlets to which distribution lines can be connected. Thus, the coolant flow pattern through each unit would be defined under all operating conditions. However, the required coolant flow rates for any unit would vary, depending on the available coolant inlet temperature. Instead of defining an ambient temperature as a requirement for satisfactory thermal operation, a practice that is undesirable even for most present equipment, thermal characteristics of each unit as functions of coolant inlet temperature would be established by experimental and analytical evaluation procedures.

Elaborate test apparatus for simulation of altitude pressure and temperature conditions will be unnecessary since only forced-circulation flow systems would be applicable. The thermal performance can then be correlated with the weight flow rate of the specified coolant, independent of the coolant density. For example, in Fig. 6 is shown the method of presenting the characteristics of a unit having cooling airflow over the internal component surfaces.[1] A representative temperature, the so-called effective component temperature, is chosen as a measure of component temperature level. The effective temperature is the average value of the surface hot-spot temperatures of compo-

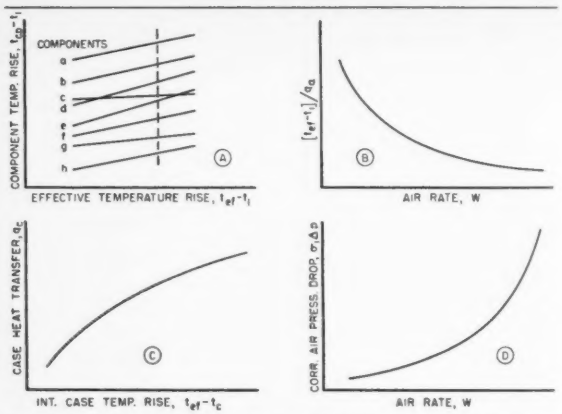


FIG. 6. Generalized thermal characteristics of forced-air-cooled electronic unit.

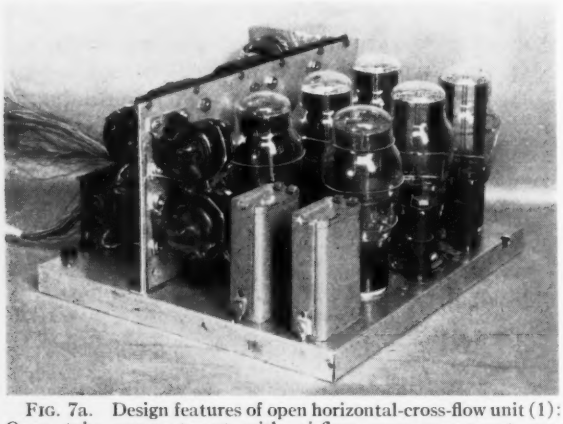


FIG. 7a. Design features of open horizontal-cross-flow unit (1): Open tube compartment with airflow over component surfaces.

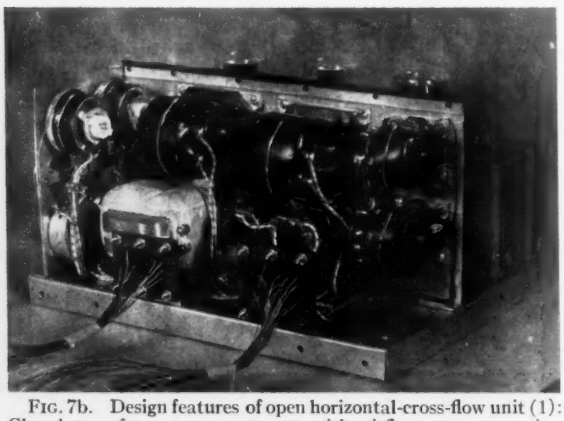


FIG. 7b. Design features of open horizontal-cross-flow unit (1): Closed transformer compartment with airflow over mounting surface.

nents constituting 75 per cent or more of the unit's total heat dissipation. As shown by curve B, the ratio of the effective temperature rise above the inlet temperature to the heat-absorption rate of the air, $(t_{ef} - t_1)/q_a$, is correlated with the flow rate practically independent of air pressure and temperature. Similarly, the pressure drop of the cooling air across the unit is correlated with the air rate and depends on the density of the air at the inlet (defined by σ, its ratio to a standard density), as shown by curve D. The heat-absorption rate of the cooling air may differ from the unit's rate of heat generation if there is heat loss from or heat gain to the case of the unit. The case heat-loss rate can be correlated with the effective-to-case temperature difference, $t_{ef} - t_c$, as shown by curve C. The surface hot-spot temperature's rise above inlet air temperature of the individual components, $t_{cp} - t_1$, can be correlated with the effective temperature rise, as shown by curves A.

The types of correlation curves shown in Fig. 6 are obtainable for all coolants that, like air, have not highly variable physical properties in the range of probable available coolant temperatures. This would also include liquids, except that for each component the temperature rise would probably correlate with the effective temperature rise linearly. The thermal characteristics of externally cooled closed units can be expressed in similar manner. For them, the temperature of the external heat-exchange surface is substituted for the effective temperature in the correlation given by curve B of Fig. 6. If the case is part of the heat-exchange surface, curve C is not required, and the component temperatures can be plotted directly versus the heat-exchange surface temperature, somewhat simpler than curves A in Fig. 6. The pressure-drop characteristics of the external cooling passage would be expressed in the manner shown by curve D in Fig. 6.

When thermal data as presented in Fig. 6 are available for every unit, the design of individual, group, or central cooling systems is considerably facilitated. The required coolant supply rate to each unit is readily determined from the characteristic curves on basis of the known allowable effective component or external heat-exchange surface temperature and the available coolant temperature. When the cooling mechanism is internal and the installation environment is such that heat loss from or heat gain to the case is expected to be appreciable, the use of the characteristics in Fig. 6 involves a trial-and-error calculation process.

Cooling Design of Electronic Units

More than any other factor, the cooling design of each electronic unit operating as part of a system influences the overall requirements of coolant flow rate, coolant pressure, and power expended to convey the coolant over equipment heat-exchange surfaces. Typical results attainable by application of various methods are discussed in the following. Experimentally determined cooling characteristics[4] of several units fulfilling the same electrical function and consisting of the same electronic components are used as comparative data on the different cooling design methods. To some extent, the results are affected by the type of unit and components, but they are qualitatively significant for electronic equipment in general.

Seven different cooling design configurations of a power supply unit having a heat-dissipation rate of

330 watts are shown in Figs. 7 to 11. Each closed unit has an external heat-exchange surface of the same dimensions. This allows comparison of the effects of different internal designs on cooling requirements resulting from the different heat-exchanger surface temperatures. The open units can be compared with each other quantitatively and with the closed units qualitatively.

Open Units

Two views of the chassis of an open unit in which airflow is produced horizontally across the tube surfaces are shown in Figs. 7a and 7b. The airflow through the tube compartment, shown in Fig. 7a, also cools the vertical mounting surfaces of the transformers. This is adequate to maintain required transformer temperatures, and, therefore, the compartment shown in Fig. 7b is closed. The heat concentration of the unit is 1,020 watts per cu.ft. In order to maintain the 6AS7 regulator tubes in the flow passage at the specified surface temperature, the other tubes are overcooled.

The features of a unit in which airflow is produced vertically upward and essentially parallel to the tube surfaces are shown in Figs. 8a, 8b, and 8c. As shown in the schematic of Fig. 8a, air is admitted selectively only around the tube bases through ports (C) of various dimensions located in the chassis (B) and is discharged through ports (E) in a cover plate. The chassis ports are shown in Fig. 8b. There is no air admitted in the vicinity of the transformers, which are installed on the side surfaces as shown in Fig. 8c. By taking into account the magnitude of heat dissipation and the orientation of the internal structure of individual tubes when proportioning the air supply ports, essentially equal tube surface temperatures are produced. There is sufficient air diffusion into the transformer section and conduction from the vertical mounting surfaces to the cooled cover plate to maintain the transformers within allowable temperature limits. The heat concentration of the unit is 1,460 watts per cu.ft. Because of the selective air admission and the resulting operation of practically all components near their allowable surface temperature, this unit requires considerably less airflow than the horizontal cross-flow unit.

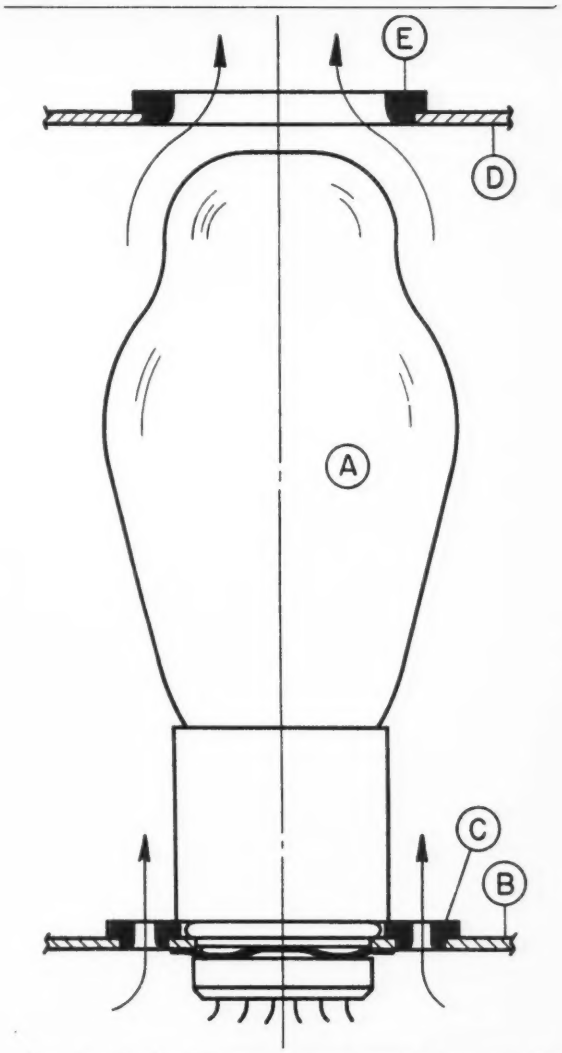
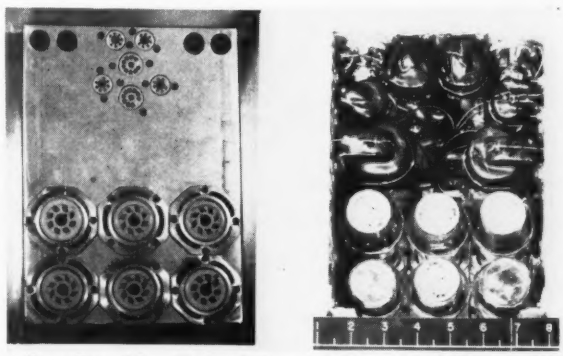


FIG. 8a. Design features of open vertical-flow unit (2): Schematic of cooling air supply and discharge port arrangement for tubes.



FIGS. 8b and 8c. Design features of open vertical-flow unit (2). (b) Supply ports in chassis. (c) Component arrangement of unit.

Closed Conduction-Cooled Unit

In Figs. 9a, 9b, and 9c are shown design features of a unit that is closed and utilizes principally conduction to transfer heat from the components to a heat-exchanger plate. The cooling plate shown in Fig. 9b has passages for forced or induced flow of external air. The heat concentration of the unit is 1,350 watts per cu.ft. While the conduction paths through the vertical mounting surfaces shown in Fig. 9a are adequate to convey the heat dissipation of the transformers to the cooling plate attached to the top flange of the unit, the tubes require shields to conduct heat from their envelopes to the cooling plate. In Fig. 9c, the configuration of a conduction shield assembly for the 6AS7 tube, which is operated with an average heat dissipation of approximately 2 watts per sq.in. of total bulb surface, is shown. The main shield (B) is screwed into the cooling plate and has a slotted copper insert (D) that

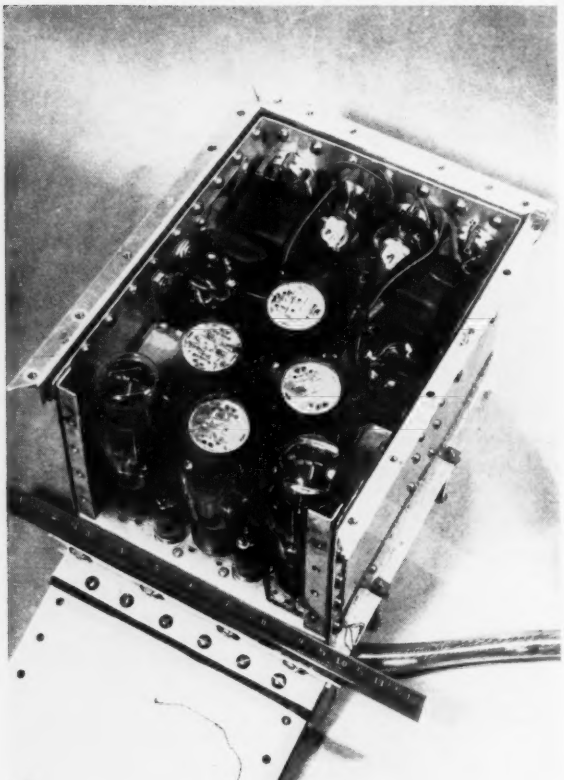


FIG. 9a. Design features of closed conduction-cooled unit (3): Component arrangement of unit.

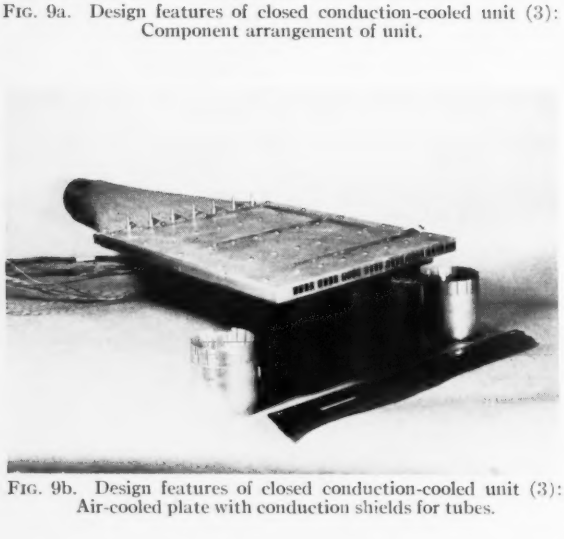


FIG. 9b. Design features of closed conduction-cooled unit (3): Air-cooled plate with conduction shields for tubes.

centers the tube and aids in conducting heat. An auxiliary shield (E), held in position by a tube clip (F), conducts heat from the tapering lower part of the bulb to the main shield (B). Such complications are necessary because deviations in bulb sizes require an air gap between tube (A) and shield (B) of at least $^{1}/_{16}$ in. This reduces gaseous conduction. To transmit heat by radiation even at a rate of only 1 watt per sq.in. and with an average bulb temperature of 160°C., requires a shield temperature below 30°C. For a hot-spot temperature of 160° C., the shield temperature must be considerably lower.

The auxiliary shield (E) is unnecessary for the other tubes in the unit. For the average heat dissipation of 2 watts per sq.in. of bulb surface, the shield structure shown in Fig. 9c is not sufficient to produce a temperature gradient of less than 150°C. between the tube hot spot and the plate. By filling the spaces between tube and shields with silicone grease having a thermal conductivity approximately five times that of air, the temperature gradient can be reduced to 100°C. Thus, corresponding to a specified hot-spot temperature of 160°C. for the 6AS7 tube, the heat-exchanger surface temperature would be 60°C.

While the method of cooling by conducting heat to a cooling plate is extremely suitable for components like transformers which have high internal thermal conductance, the cooling of glass tubes of significant heat dissipation can only be accomplished by complicated design of the conduction shields and the use of silicone greases as intermediaries. The weight of the shields in this unit is 3 lbs.

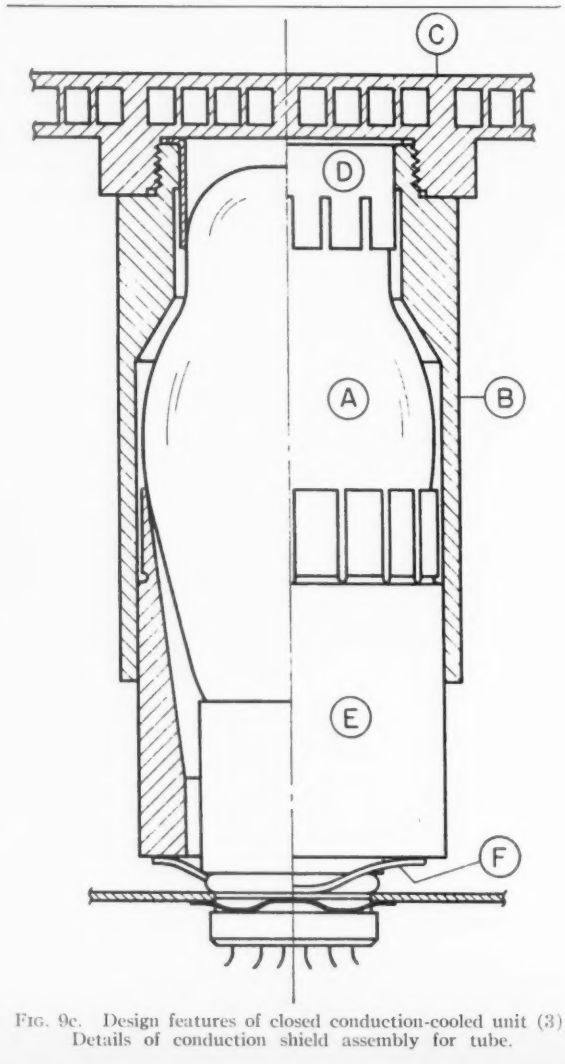


FIG. 9c. Design features of closed conduction-cooled unit (3): Details of conduction shield assembly for tube.

Sealed Internally Forced-Air-Cooled Unit

In Fig. 10 is shown the schematic of a sealed unit utilizing the vertical flow pattern of the open unit of Figs. 8a, 8b, and 8c and a heat exchanger with internal and external cooling passages having the same characteristics as the cooling plate shown in Fig. 9b. It is indicated that the vertical flow pattern is most suitable for the design of sealed units with external heat exchangers. The thermal characteristics of this unit are derived by combining the performances of the open unit and of the cooling plate. An increase in the heat dissipation of the entire unit by about 11 per cent results from the input to the blower motor. The internal circulating air temperature at the heat-exchanger outlet is assumed at 120°C. Then, to maintain the 6AS7 tube at a hot-spot temperature of 160°C., the plate temperature necessary for the required internal air rate is 90°C. Thus, by proper chassis design, using selective air distribution, this more conventional method of cooling sealed units can result in smaller temperature gradients between tubes and external cooling air than may be achieved with the conduction-to-cooling plate method exemplified by the unit of Figs. 9a, 9b, and 9c.

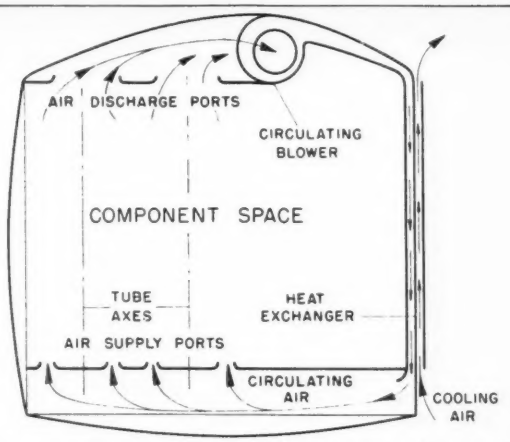


FIG. 10. Schematic of sealed vertical-flow unit with case heat exchanger (4).

Liquid-Filled Units

The heat concentration of the unit is again 1,350 watts per cu.ft. when the components are arranged on a chassis, shown in Fig. 11a, which is suitable for a cylindrical case. The component spacings are reduced, but the cylindrical case does not permit as effective a space utilization as the prismatic case. The configuration is suitable for liquid cooling at high pressures and is here also evaluated for other methods of liquid cooling. By filling the unit with mineral oil, as shown schematically in Fig. 11b, the temperature gradient between the hot spot of the 6AS7 tube and the case is reduced to 40°C. A heat-exchange surface on the upper portion of the cylindrical case surface would then operate at 120°C. This implies an oil temperature of about 140°C. and indicates that, in order to realize the full advantage of small temperature gradients that are attainable by the use of liquid-cooling techniques, the temperature-sensitive components (here the capacitors) must be capable of operating near the surface temperature of the heat-producing components. Filling the unit with oil adds 7 lbs. to its weight.

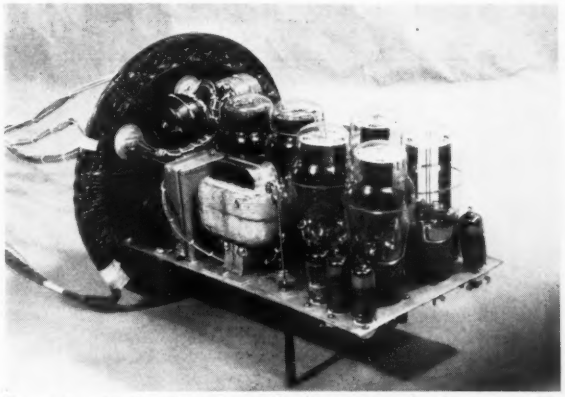
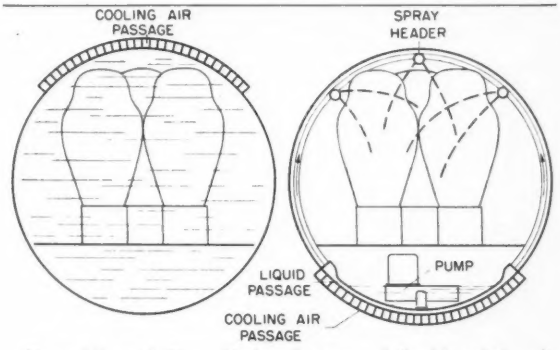


FIG. 11a. Design features of liquid-cooled units (5, 6, and 7): Chassis for cylindrical case.



FIGS. 11b and 11c. Design features of liquid-cooled units (5, 6, and 7). (b) Schematic of liquid-filled unit with case heat exchanger (5 and 6). (c) Schematic of spray-cooled unit with case heat exchanger (7).

The schematic of Fig. 11b is also applicable to the configuration used when the unit is filled with a liquid of high vapor pressure, for example, Freon-11 which has good electrical properties and in which heat transfer from component surfaces occurs by the mechanism of submersed boiling. This heat-transfer mechanism reduces the temperature gradient between the hot spot of the 6AS7 tube and the case to about 22°C. Thus, the heat-exchanger surface at the top of the unit would operate at 138°C. This temperature gradient is on the order of that required with other fluids having good convective properties such as various fluorocarbon compounds. The latter, however, do not have the Freons' disadvantage of high vapor pressures that are encountered when the liquid is maintained near the limiting surface temperatures of the heat-producing components and which necessitate heavy case construction. The weight added to the unit by filling with Freon-11 is 10 lbs. The comparable weight of some of the fluorocarbons would be 12 to 14 lbs.

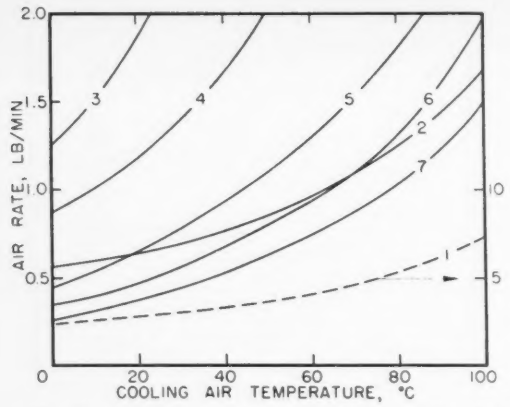


FIG. 12. Required airflow rates of comparable cooling designs.

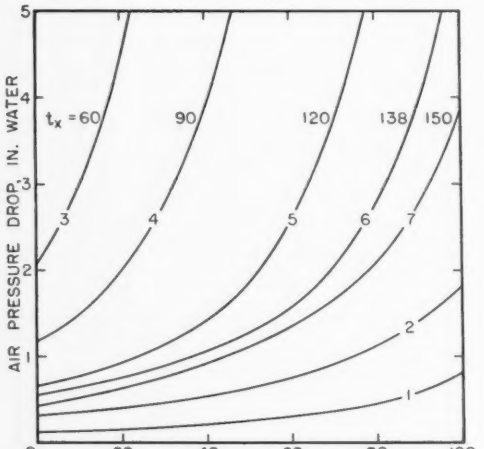


FIG. 13. Pressure drop of comparable cooling designs at 40,000-ft. altitude pressure (t_x = heat exchanger surface temperature, °C.).

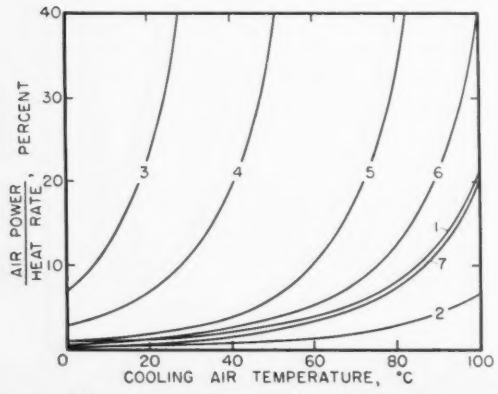


FIG. 14. (Air power)-to-(heat rate) percentage of comparable cooling designs at 40,000-ft. altitude pressure.

Spray-Cooled Unit

The disadvantage of large weight increase is largely overcome by spray cooling with a liquid rather than immersing all components in it completely. The schematic of Fig. 11c indicates the system applied to the unit and the most convenient location of the circulating pump and the external heat exchanger. The latter's surface is at 150°C. when the hot spot of the 6AS7 tube is at 160°C. and mineral oil is used as spray coolant. Because of the small overall temperature difference that is so obtained, the use of evaporative coolants is not necessary in spray systems. The power economy that can be realized because of the smaller circulation rate required for an evaporative coolant is insignificant since it would change the heat dissipation of the unit less than 1 per cent. The weight of the pump and spray distribution system would be about one-third that of the oil contained in the liquid-filled unit. The system has an element of unreliability in the possibility of spray nozzle clogging. This can be prevented by the use of larger nozzles and higher spray rates. In comparison to the unit's heat-dissipation rate, the resulting increase in pumping power requirements would be insignificant.

Comparison of Cooling Methods

The seven different types of cooling are compared in Figs. 12, 13, and 14 for required airflow rate, pressure drop, and cooling power required to achieve a 160°C. hot-spot temperature for the 6AS7 tube in each unit, over a range of cooling air temperature at 40,000-ft. pressure altitude. The curves are labeled with reference to the unit numbers indicated in the captions of Figs. 7 to 11.

The highest air rate shown in Fig. 12 is for the open horizontal-cross-flow unit designed with component spacings for minimum cooling power attainable with this cooling method.[5] As seen in Fig. 13, its pressure drop is the lowest. However, because of the large air rate its cooling power is greater than for the open vertical-flow unit. The latter type requires approximately one-fourth the air rate, which gives, even though the pressure drop for the same air temperature is more than twice as great as that of the horizontal-cross-flow unit, a substantially lower cooling-power requirement. The significance of this is indicated in Fig. 14 by the air temperatures that can be used for the two types at equal cooling power. The greater the permissible air temperature, the more suitable is the unit for application in high-speed aircraft. In that respect the open vertical-flow unit is superior to all other types.

Among the five closed types utilizing the same external heat-exchange surface, the air rates in Fig. 12, the pressure drops in Fig. 13, and the cooling-power requirements in Fig. 14 increase in the same order. For a given cooling air temperature, they increase with lower heat-exchanger surface temperature required by the given cooling method. Thus, in the order of decreasing cooling economy, the units should be listed as (1) liquid

spray, (2) Freon-filled, (3) oil-filled, (4) sealed with vertical internal airflow, and (5) conduction-to-cooling surface. For example, at 10 per cent cooling power—i.e., the air power is 33 watts—the permissible cooling air temperatures for the units in the order listed are 86°, 75°, 60°, 28°, and 7°C., respectively. In terms of cooling system design this would normally mean the necessity of providing refrigerated air for the latter types, while simple ram-air cooling may be feasible for the liquid-cooled types, provided the flight speed does not exceed Mach 1.5 at altitudes above 40,000 ft. It is also significant to note that the liquid-spray method can be applied with the same power economy as the open cross-flow method, with the added advantage of reduced equipment size and sealing from environmental effects but probably with some increase in equipment weight. The other cooling methods for sealed units would penalize aircraft performance more than the open units because of greater air rate, pressure drop, and cooling power.

The comparison of the seven units here discussed cannot be generalized without exception. The relative merits are affected by the type of unit for which the comparison is made. However, the results should be generally applicable to units of heat concentrations greater than 1,000 watts per cu.ft., operating at a component temperature level on the order of 160°C. The open vertical airflow method appears to be superior whenever existing voltages do not require sealing. Its application in the illustrated manner may not be as readily accomplished in miniature construction but is practical when applied to subassemblies. For units that must be sealed from the flight environment, the liquid-spray method appears to be thermally superior. Its perfection for acceptable reliability requires the development of suitable mechanical components. For realization of the optimum in equipment size reduction which potentially can be accomplished with this cooling method, the development of a new line of miniature electronic components of heat-dissipation rates on the order of 5 to 10 watts per sq.in. of surface would be desirable. It should then be feasible to design high-power air-borne electronic equipment so reduced in size that heat concentrations of 3,000 watts per cu.ft. would be obtained which could readily be coped with by the spray-cooling method.

Conclusion

It is hoped that this paper helps to indicate the general lines of approach to the solution of the cooling problem in air-borne electronic equipment. The design of cooling systems and of electronic equipment are inseparably related. It will be necessary to base the design of future electronic equipment on specifications of coolant properties rather than of environmental conditions. In the development of electronic equipment to provide required operational functions with least penalty on aircraft flight performance, the greatest contribution can be made by the equipment designer by use of rational design methods and application of techniques that result in least temperature gradients between component and equipment cooling surfaces.

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What Magnetic Amplifiers Can Do to Increase Aircraft Reliability

GEORGE F. SCHROEDER*
Ford Instrument Company†

Advantages of Magnetic Amplifiers

Ruggedness and Reliability

The amplifying elements of magnetic amplifiers are saturable reactors that physically resemble transformers but which utilize the magnetic properties of special core materials for amplification. Since magnetic amplifiers contain no moving or fragile parts but consist mainly of transformer-like reactors and metallic rectifiers, their chief advantage is found in their ruggedness and reliability. They can withstand vibration and shock equally as well as a transformer. They can be physically isolated and sealed since they are practically maintenance-free. In fact, it has been found that the life of magnetic amplifiers is usually limited by the life of the rectifiers in the system. Uninterrupted service of at least 10,000 hours of operation—which at present is the minimum life of most rectifiers—is general. By de-rating the rectifiers, the life of magnetic amplifiers can be extended almost indefinitely.

No Warmup Time

Another advantage is the complete lack of a starting period. No warmup time is required. Thus, armament control systems, navigational systems, booster and control systems, and all other types that use magnetic amplifiers can be operated immediately to meet any emergency situation. They need not be continuously energized in anticipation of their use at some critical moment. In addition, "zero warmup time" may be credited with saving stand-by power, and, as a result, the active service life of the unit is further extended.

No Cooling Problems

Heat dissipation, a constant problem in the design of vacuum tube amplifiers, presents only minor difficulty to the magnetic amplifier designer. Since there are no filaments to heat, there is saving in power. Furthermore, since less cooling is needed, a design more compact than an equivalent electronic design can be made whenever power amplification is involved. This feature of compactness becomes more evident when we realize that magnetic amplifiers require no "B" power supply.

Presented at the Electronics Session, Twenty-First Annual Meeting, I.A.S., New York, January 26–29, 1953.

* Assistant Chief Engineer.
† Division of The Sperry Corporation.

Criteria for Evaluating Magnetic Amplifiers

For application purposes, magnetic amplifiers can be evaluated on the basis of the following criteria: sensitivity, gain, linearity, response time, and stability.

Sensitivity

Amplifiers sensitive to signals less than 1 milliwatt have been devised. These include magnetic amplification of such low energy signals as those derived from thermocouples, control transformers, potentiometers, and various sensing devices.

Gain

Power gains of single-stage amplifiers have gone as high as 1,000,000. Although there is no theoretical limit to single-stage power gains, practical considerations usually limit amplification to much lower values. The controlling factors, in addition to those of fabrication, are linearity, circuit stability, and signal-to-noise ratio.

Where relatively large gains are required together with good linearity, stability, and low signal-to-noise ratio, it is necessary to cascade two or more stages. Ford Instrument Company has developed circuits that permit the cascading of a large number of stages. The input stage is operated at low power and voltage levels, thereby increasing sensitivity over that of an equivalent single-stage amplifier. By working with lower voltages, smaller rectifiers can be used in each stage. In addition, voltages induced in the control windings are minimized, facilitating their reduction to a negligible level at the input signal source by the balancing effect of the amplifier circuits.

Linearity

Linearity of a typical half-wave bridge stage is shown by the gain curve in Fig. 1. There is a constant output-input ratio up to 80 per cent of the output load, and above 80 per cent the curve becomes nonlinear. Depending upon the requirements of the particular circuit, linearity can be extended over a larger range of input signals by the use of negative feedback at the cost of some gain.

Response Time

The response time, or time constant, of an amplifier is a measure of the speed with which its output follows

a change in input. One particular definition is the time required for the output to reach approximately 63 per cent of its final value in response to a step change in the input. For most applications, it is desired that the amplifier time constant be as small as possible and that it be symmetrical—that is, the same for both increasing and decreasing signals. By suitable design techniques, magnetic amplifiers can be made to satisfy the response time requirements for almost every application.

The response time for a single-stage self-saturating circuit has a theoretical minimum of $^1/_2$ cycle, unless recourse is made to special techniques, since the rectifier in series with the anode winding de-energizes the reactor for $^1/_2$ cycle. It is evident, then, that a 400-cycle system will respond in less than one-sixth the time of a 60-cycle system. At higher frequencies, the effect of the shunt capacitance of the common types of rectifier cells becomes appreciable; this gives rise to circuit instability. If germanium crystal or similar rectifiers are used, however, it is possible to go up to the megacycle range.

In order to develop circuits that have response times approaching the theoretical minimum of $^1/_2$ cycle, it is necessary to minimize the magnitude of the circulating currents. With large circulating currents present, the system takes longer to reach its steady state. Also, the system suffers losses in gain and sensitivity. To overcome this difficulty special circuits have been devised to minimize this effect.

Frequency Response

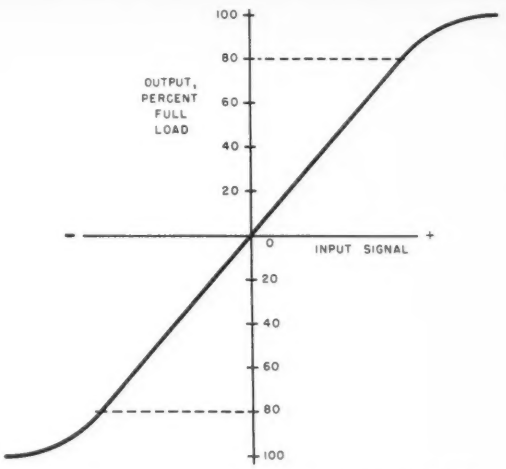
A more complete representation of amplifier performance than response time is given by the frequency-response characteristics of Fig. 2. This is a plot of such data for a single-stage circuit having a modulated 400-cycle input signal and is typical of a number of half-wave single-stage circuits made by Ford Instrument Company. The abscissa scale represents modulation frequencies; the left ordinate scale gives the ratio of output to input voltage, and the right ordinate scale shows phase shift.

The amplifier output is seen to be essentially flat to 40 cycles—that is, to 250 rad. Over most of this range, the phase lag is less than 40°. These characteristics lend themselves quite readily to servo applications. It should be noted that the phase lag is the resultant of a fixed time delay and the normal minimum phase characteristic. This may be of importance in some servo applications.

Circuit Stability Criteria

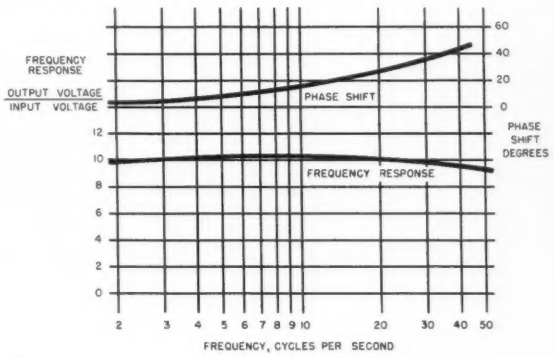
Circuit stability may be judged by the effects of variations in frequency, line voltage, temperature, and age.

In most of the older magnetic amplifier circuits, variations in supply voltage had a decided effect on the output. By using bridge-type circuits, we are able to reduce appreciably the effects of line voltage and frequency variations.



LINEARITY CHARACTERISTICS OF A MAGNETIC AMPLIFIER

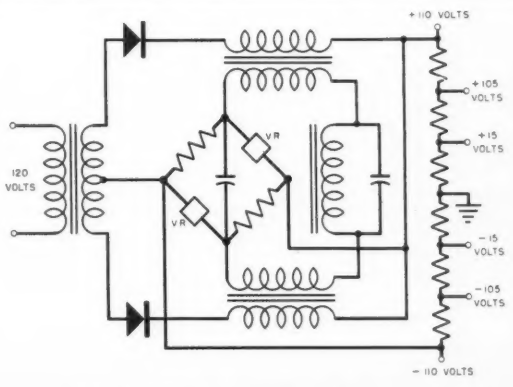
FIG. 1.



FREQUENCY RESPONSE CURVE

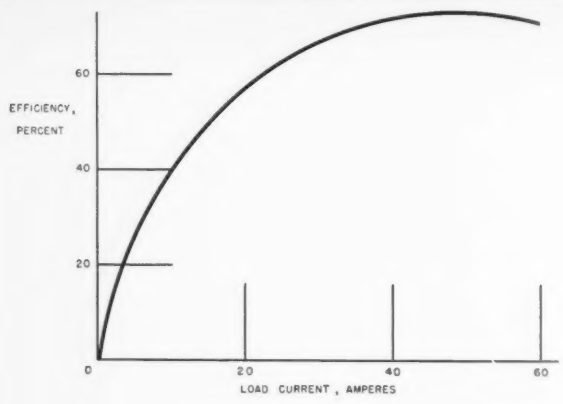
(SINGLE PHASE BRIDGE CIRCUIT, 400 CYCLES)

FIG. 2.



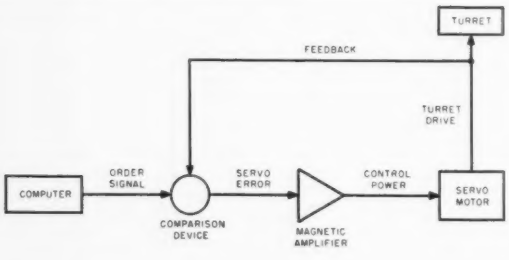
SINGLE PHASE FULL-WAVE RECTIFIER CIRCUIT

FIG. 3.



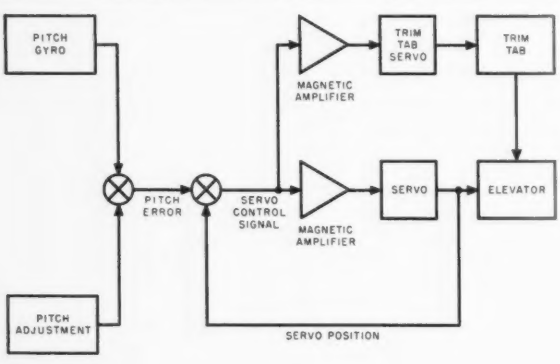
TYPICAL CONVERTER EFFICIENCY

FIG. 4.



TURRET DRIVE SYSTEM USING MAGNETIC AMPLIFIER

FIG. 5.



AUTOPILOT USING MAGNETIC AMPLIFIERS

FIG. 6.

The effect of temperature on rectifier leakage and the effect of rectifier aging have been reduced by shunting the rectifier with a resistor having a lower resistance than the back resistance of the rectifier itself. In this way, the two resistances in parallel are substantially constant.

APPLICATIONS OF SATURABLE REACTOR

The saturable reactor may function in one of several capacities—as an amplifier, as a relay device, or as a voltage or frequency sensing element. Consequently, the reactors are applicable to many diverse types of air-borne equipments such as navigational computing instruments, armament control systems, rocket control devices, power-driven gun turrets, radar antenna drives, control surface and landing-gear systems, frequency changers and converters, autopilots, boosters, and radar.

Unfortunately, security regulations prevent the discussion of many of these applications. However, some applications have appeared in the press, and others have been declassified and may be discussed; perhaps from these an indication of scope may be gained.

Converter

A problem easily solved by the magnetic amplifier is that of converting a.c. power to accurately regulated d.c. power. As an example, Fig. 3 shows a single-phase full-wave rectifier circuit. There are no tubes or moving parts present. At the output, the regulated voltage is applied across a voltage divider—regulation is within 1 per cent. The efficiency curve for a converter designed for 50 amp. d.c. output is shown in Fig. 4. At design load, the efficiency is better than 70 per cent. If design calls for less accurate regulation, the efficiency can be increased.

Turret Drive

Another magnetic amplifier application is illustrated by the turret-drive system shown in Fig. 5. The order signal from the computer is compared with the turret-drive response signal to form an error signal, which controls the magnetic amplifier. The amplifier, in turn, powers the servomotor and thus the turret. This system has proved to be highly accurate.

Autopilot

The use of magnetic amplifiers in autopilots is particularly advantageous from the point of view of stability and continuity of operation, and of resistance to vibration and shock, which conditions are indigenous to military aircraft. A block diagram of an autopilot using magnetic amplifiers is shown in Fig. 6. The difference between the pitch error and the servo position is the input to each of two magnetic amplifiers; one controls the trim tab servo, and the other the elevator servo. The magnetic amplifier could just as easily be included in an autopilot system to control the lateral and roll attitudes and the throttle controls.

In connection with servomechanism applications, we can mention that magnetic amplifiers have been developed which directly control servomotors ranging in power from $^1/_2$ watt to 5 hp. Considerably larger amounts of power can be controlled if required.

Pulse Generator

By cascading series circuits of saturable reactors and capacitors as shown in Fig. 7, a pulse generator is designed which gives a high rate of discharge. The pulse

width can be made small depending only on the number of cascaded stages; limitations are somewhat imposed by the departure of the performance of the practical core from that of the ideal core. The magnetic pulse generator is particularly applicable to radar where it can replace the troublesome thyratron type of modulator. Such a magnetic modulator is almost free of pulse "jitters."

Time Delay or Smoothing Unit

For some installations, a large rather than a small response time may be required. This is true when the amplifier is to operate as a time-delay unit or is to produce a smoothing action. By incorporating separate shorted windings on the core, either function may be accomplished.

Voltage Reference

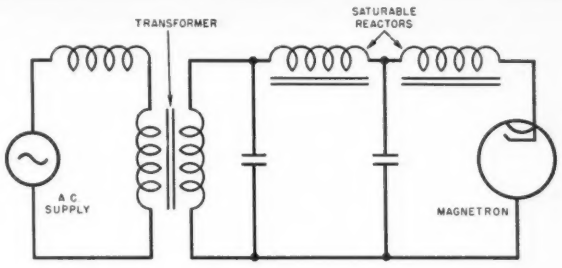
Since saturation of a core occurs at a fixed voltage that can be made quite independent of time and temperature, it is possible to use a saturable reactor as a precise voltage reference. It is believed that this device can be used to improve the voltage regulation of aircraft electrical systems.

Relay

The last application to be discussed is that of the relay. A relay type of saturable reactor circuit is shown in Fig. 8. Its operation is such that the circuit is either on or off, either completely saturated or not at all. Reference to Fig. 9 shows the effect of feedback on the output load response. Note that as the feedback becomes more positive, the slope of the output-input curve becomes more nearly vertical. A point is finally reached where an extremely small control current causes the output load to jump to its maximum value. By biasing, the curves can be shifted so that operation centers about zero signal current or any other value required.

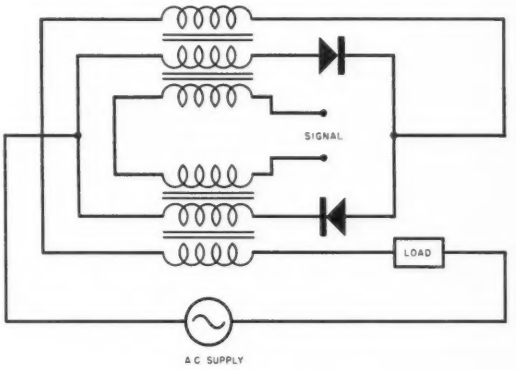
Conclusion

Today, the magnetic amplifier has become standard equipment in many installations that had previously required shock-mounted electronic amplifiers. The future of the device is wide. We can look forward to its operating up to the megacycle range, to its increased used as a computing element, and to its increased application in the field of servomechanisms. This future is bound up with the development of even better core materials, more efficient rectifiers, and, of course, the ability of the engineers to devise new and better circuitry.



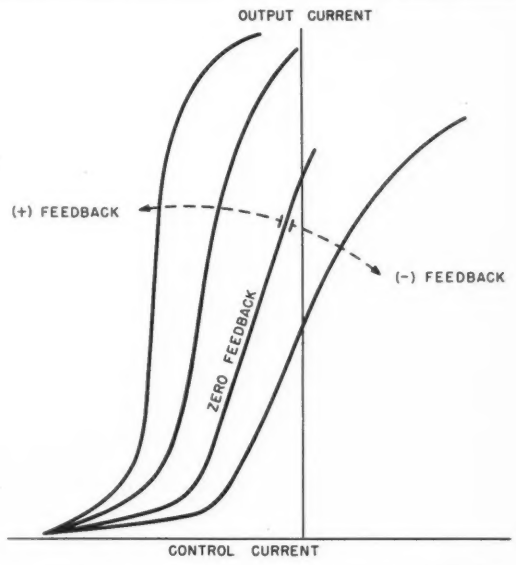
SATURABLE REACTORS USED AS PULSE GENERATORS

Fig. 7.



SATURABLE REACTOR RELAY CURCUIT

Fig. 8.



SATURABLE REACTOR RELAY CHARACTERISTICS

Fig. 9.

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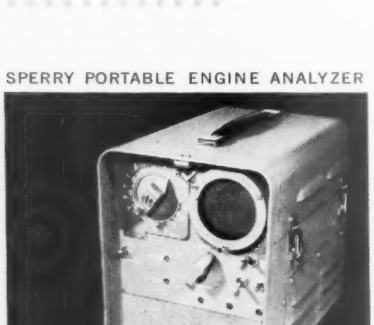

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Asymptotic Forms of Shock Waves in Flows over Symmetrical Bodies at Mach 1

By

Capt. David T. Barish and Dr. Gottfried Guderly

Wright-Patterson Air Force Base

The forms of shock waves in flows at Mach 1 at large distances from a symmetrical body are considered for planar and for axisymmetric flows. It has previously been shown that for the flow upstream of such shocks similarity solutions exist. It is found that the assumption of similarity solutions downstream of the shocks is consistent with the shock relations in the transonic approximation. These facts are used to compute the flow fields at large distances from the bodies.

Bending of Thin Elastic Plates of Variable Thickness

By

Y. C. Fung

California Institute of Technology

Southwell's equations for the bending of thin elastic plates are derived from a new point of view and extended to plates of variable thickness and mixed boundary conditions. The bending and twisting moments and the transverse shear in the plate are expressed in terms of two "stress functions" U and V. The boundary conditions are such that, on an unsupported edge, the boundary values of U and V are known and, on a clamped edge, the first derivative of U, V are known. Thus, the new formulation is particularly adaptable to plates with free edges, for which the classical Kirchhoff-Love formulation expressed in terms of the deflection function is inconvenient because the boundary conditions involve the second- and third-order derivatives.

The theory is applied to a square plate with linear thickness variation (cross sections in the form of a double wedge) simply supported at two diagonal corners and loaded by a pair of equal forces at the other two corners. This loading condition is chosen for its simplicity in experimental verification that is carried out. The stresses and deflection of this plate are found by the relaxation method. The profound influence of the thickness variation on the stress distribution is shown by comparing the results with the exact solution for a plate of uniform thickness under the same loading condition. The theoretical results agree with the experiments within the estimated error of both, indicating that the formulation of the bending problems for plates of variable thickness is sound.

The influence of the thickness variation and the power of the method are further illustrated by the results for the bending of the square plate by uniform edge moments and also for a full-span solid swept wing

An Investigation of the Flow About Cones and Wedges At and Beyond the Critical Angle

By

G. W. Johnston

Institute of Aerophysics, University of Toronto

An experimental investigation has been carried out in the Institute of Aerophysics 16- by 16-in. supersonic wind tunnel to determine the extent and general nature of the subsonic field produced ahead of wedge and cone models during bow-wave detachment and beyond, where the free-stream Mach Number lies in the supersonic régime. All tests were carried out at a nominal Mach Number of 2.5 under conditions of zero lift. The extent and growth, both lateral and forward, of the imbedded subsonic field has been measured for both models at the critical angle and beyond from a series of schlieren and shadow flow photographs. The general nature of the associated subsonic field was determined over the same range from a series of pressure distributions taken at the model surface and from the measured shock-wave geometry. The pressure measurements have also been used to determine the forebody pressure drag of cones and wedges at the detachment angle and throughout the critical position of the detached region. A method has been developed which allows a complete theoretical solution of the detached subsonic flow about a wedge model. This method does not rely on a preliminary knowledge of the bow-wave geometry but is carried out in the hodograph plane.

The salient characteristics of the detached flow about both the cone and wedge models are shown. These characteristics are similar to those occurring at transonic Mach Numbers.

Please do not order Preprints of these papers at this time.
See page 96 for Preprints that are immediately available.

Stress Analysis of Sheet Stringer Panels with Cutouts

By

Harvey G. McComb, Jr.

Langley Aeronautical Laboratory, N.A.C.A.

A method is presented for determining the stresses in axially loaded sheet-stringer panels having cutouts. The method is based on the use of so-called "unit perturbation" solutions that are appropriately superposed to give the effects of the cutout on the stress distribution that would exist with no cutout. The analysis of stringer reinforcements and doubler plates is carried out in a similar fashion.

Preprint No. 394

Shock-Wave Effects on the Laminar Skin Friction of an Insulated Flat Plate at Hypersonic Speeds

By

Ting-Yi Li and H. T. Nagamatsu

California Institute of Technology

An approximate theory on the phenomena of interaction between the shock wave and the laminar boundary layer on an insulated flat plate at hypersonic speeds has been formulated. Results on

the rate of growth of the boundary-layer thickness and the rate of decay of the shock-wave strength have been found which hold for $M_1^{2(2+\omega)}R_1^{-1} = O(1)$. A new set of formulas for the average skin-friction coefficient, C_F, over an insulated flat plate at hypersonic speeds has been obtained. Calculations on the basis of the new C_F formulas yield the data shown in Figs. 5 and 6. Contrary to the conventional theory that predicts a steady decrease in C_F as M_1 increases, the present results indicate that C_F may increase with M_1 at hypersonic Mach Numbers.

Equations for the Loading on Triangular Wings Having Supersonic Leading and Trailing Edges Due to Various Basic Twist Distributions

By

Julian H. Kainer

Republic Aviation Corporation

The linearized supersonic flow theory has been applied to determine the potential pressure and span-load distributions due to various basic twist distributions on triangular wings with leading and trailing edges ahead of the Mach cones.

Generalized equations in closed form are presented for the potential pressure and span-load distributions due to constant, linear, parabolic, and cubic twist distributions. In addition, design charts for the rapid evaluation of the pressure and span-load distributions are presented.

The results are directly applicable to rigid wings with built-in twist and may be applied to the aeroelastic problem by means of superposition of the basic solutions. In addition, a means of obtaining pressure distribution on wings in the presence of bodies is suggested.

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Geon helps protect new lead-wire assembly

AIRCRAFT engine lead-wires for carrying high voltage from the transformer coil to spark plug were rubber covered nickel braid. They frequently deteriorated quickly from the effects of ozone and engine heat. Result —*higher* maintenance costs, *lower* safety factor.

After months of experimenting, engineers came up with the answer: a lead-wire with an inner lining of plastisol made from Geon paste resin, plus two other layers of plastisol between the nickel braid.

This lightweight, vinyl plastic impregnated lead-wire has the strong, waterproof, *ozone and heat-resistant* protection that was needed. A flexible metal tube insert for enclosing the wires is no longer required. And this Geon-helped lead-wire also resists the effects of *mineral spirit solvents* which are flushed on the engine during cleaning operations.

Plastisols made from Geon paste resin can be molded, cast, coated or dipped. They can be made resistant to oils, greases, heat and cold, abrasion and many chemicals. Perhaps Geon paste resin, or other Geon materials, can help you improve or develop more saleable products. For technical bulletins, please write Dept. HF-5, B. F. Goodrich Chemical Company, Rose Building, Cleveland 15, Ohio. Cable address: Goodchemco. In Canada: Kitchener, Ontario.

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News of Members

(*Continued from page 35*)

Communications Service, Mountain Home A.F.B., Idaho. Formerly, Student Officer, Communications Electronics Staff Officers Course, Air Command and Staff School, Air University, Maxwell A.F.B., Ala.

Second Lieutenant Guido J. Frassinelli, U.S.A.F. (T.M.), Wright Air Development Center, Wright-Patterson A.F.B., Ohio. Formerly, Engineer, Aero-Elastic and Structures Research, Massachusetts Institute of Technology.

Second Lieutenant Joseph Gentile, U.S.A.F. (T.M.), 3415 Technical Training Wing, Air Training Command, Lowry A.F.B., Colo. Formerly, Test Engineer, Wright Aeronautical Division, Curtiss-Wright Corporation.

A. La Vielle Lawbaugh (A.F.), Supervisor, Preliminary Design Group, Aerophysics Department, North American Aviation, Inc. Formerly, Design Specialist, North American.

Carson E. Lebo, Jr. (T.M.), Engineering Design and Layout, Chase Aircraft Company. Formerly, Senior Engineering Draftsman, The Glenn L. Martin Company.

John W. Mazur (M.), Chief Design Engineer, Doman Helicopters, Inc. Formerly, Senior Project Engineer, Rotary Wing Branch, Flight Test Division, N.A.T.C., Patuxent River, Md.

Major Ralph D. McKee, U.S.A.F. (T.M.), Navigator, 370 Bomb Sq., 307 Bomb. Wing, A.P.O. 239-1, c/o P.M., San Francisco, Calif. Formerly, Project Officer, Aircraft Lab., Wind Tunnel Branch, Wright Air Development Center, Wright-Patterson A.F.B., Ohio.

Walter G. E. Mosebach (A.F.), Manager, Product Engineering Department, Piloted Aircraft Engineering Division, Goodyear Aircraft Corporation, Goodyear Tire & Rubber Company. Formerly, Manager, General Aircraft Design, Goodyear Aircraft Corporation.

W. S. Mount (M.), Manager, Aviation Department, Socony-Vacuum Oil Company, Inc. Formerly, Engineer, Socony-Vacuum.

Dr. Richard W. Porter (M.), General Manager, Guided Missile Department, Aeronautic & Ordnance Systems Division, General Electric Company. Formerly, Engineer—Special Projects Engineering, G-E.

Grady M. Slagle (T.M.), Research Assistant, Project Meteor, and Graduate Student in Aeronautical Engineering, Massachusetts Institute of Technology. Formerly, Research Engineer, Mechanical Laboratory, Southwest Research Institute.

Miss Franki L. van der Wal (T.M.), Associate Engineer, Reaction Motors, Inc. Formerly, National Research Council Fellow in Aeronautics, Royal Institute of Technology, Stockholm, Sweden.

John M. Warner (T.M.), Engineer, Aerodynamics Department, The de Havilland Aircraft Company, Ltd. Formerly, Project Engineer, British European Airways.

Claude R. Woodard (T.M.), Assistant Flight Test Engineer, Flight Research Department, Cornell Aeronautical Laboratory, Inc. Formerly, Design Engineer, Staff Research and Development, Thompson Products, Inc.

American Helicopter Society News

Ninth Annual Forum

The Ninth Annual Forum of the American Helicopter Society is scheduled to be held in Washington, D.C., from May 14 to 17. It will be climaxed by a helicopter air show, which will be a part of the Armed Forces Day celebration.

Headquarters for the Forum will be at the Mayflower Hotel, where technical sessions will be held on May 14 and 15 and where the annual Honors Night Banquet will take place on May 16. Display space for company exibits will be provided in the lobby of the Mayflower.

Guests from England and France are expected to participate in the technical discussions with American designers of helicopters.

Charles W. Lefever, of Prewitt Aircraft Company, is serving as Chairman of the Ninth Annual Forum.

New Constitution Ratified

The new constitution for the American Helicopter Society has been ratified by an overwhelming vote. President T. R. Pierpoint reports that a final count of the ballots showed 130 in favor of the draft and nobody voting nay. Ten unmarked ballots were received.

Members of the committee who worked on the new constitution were Ed Katzenberger, of Sikorsky; C. L. (Les) Morris, of Kaman; and Paul Stanley, of the Autogiro Company of America.

Prospective Japanese Members

As the result of a recent trip to Japan by Harry S. Pack, Vice-President of Piasecki Helicopter Corporation, A.H.S. may soon have some new members in that country. Pack was entertained by the Japan Helicopter Society and stirred up some interest in the American program. Harry Lounsbury has followed up with a letter to Japan outlining our activities and inviting the rotary-wing fans to sign up. A good supply of membership blanks was forwarded.

Mid-Eastern Region Meeting

A.H.S. members of the Mid-Eastern Region recently met in Upper Darby, Pa., to hear L. S. Guarino, of the Philadelphia Navy Yard's Aeronautical Instruments Laboratory, discuss "Automatic Control and Stabilization of Helicopters."

In his talk, Guarino disclosed that an automatic engine-speed controller can be used to maintain constant engine and rotor r.p.m., thereby relieving the pilot of the task of making r.p.m. corrections when collective pitch is varied.

He said the Navy laboratory is evaluating this technique with encouraging results.

Guarino predicted that the device will be accepted by pilots with more enthusiasm than the automatic pilot on helicopters.

"This system," he said, "can readily lend itself to complete stabilization when and if required. To incorporate complete stabilization and automatic control will necessitate merely the addition of attitude signals to the inner loop of the roll, pitch, and yaw axes and the addition of an altitude-sensing servomechanism to the collective pitch control."

"The biggest asset of the system," he said, "is the fact that it does not hamper the maneuverability of the helicopter, and overpowering the control system requires no greater effort than ordinary manual flying."

In addition to the presentation of Guarino's paper, four helicopter movies were shown: The Navy's HUP-2 Autopilot training film; Bell Aircraft's film on the Helicopter Air Services in Chicago, *Postmen of the Air;* and two from McDonnell on the "Little Henry" helicopter and the XHJD-1.

A ballot, to nominate regional members for the national officers' slate, was voted upon with the following results: President—Charles W. Lefever, Prewitt Aircraft; Vice-Presidents—Edward P. Miller, Kellett Aircraft, and Frank K. MacMahon, Piasecki; Treasurer—Monroe R. Brown, Piasecki; and Secretary—Jean Ross Howard, A.I.A.

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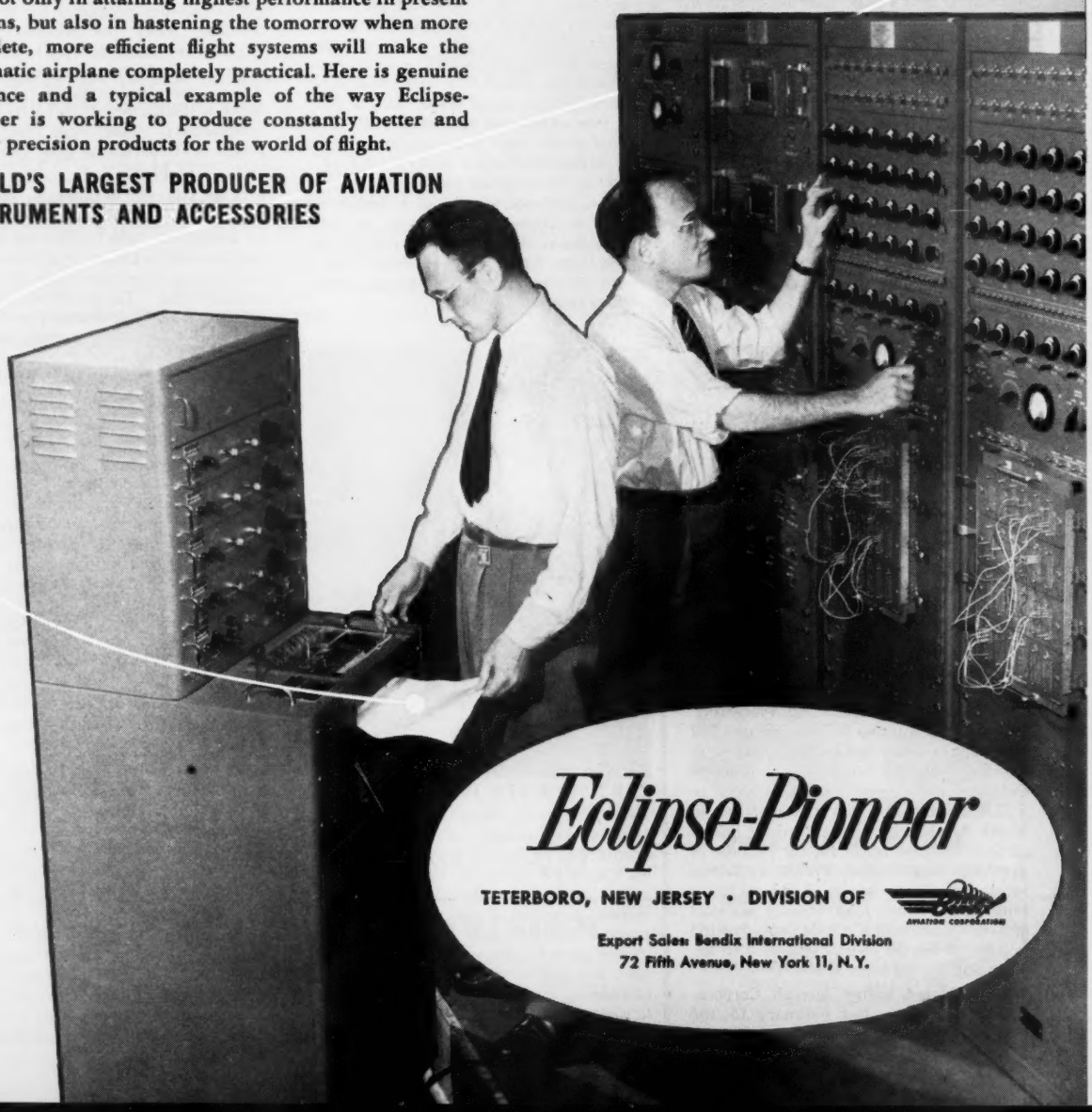

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Corporate Member News

• **Aeroquip Corporation . . .** A recently developed Anti-Icing Hose Line for jet engines is now in production. This new type of hose line conveys hot air at temperatures as high as 450°F. from the last stage of the jet-engine compressor forward to the engine nose for the purpose of preventing ice formation. Maximum operating pressure is 120 lbs. per sq.in. It is constructed of a silicone inner tube and a braided stainless-steel cover. A "Little Gem" fitting was specially developed for use with the Anti-Icing Hose Line. The fitting is so designed that the reinforcing braid of the hose alone is clamped between the socket and the nipple, while the fluid-tight seal is accomplished by separating the end of the inner tube from the braid and using it as a lip seal in an annular chamber.

• **AiResearch Manufacturing Company . . .** A description of the pneumatic temperature control unit, model No. 107614, is contained in a 4-page bulletin, *No. 2-6-1*, now available from the Los Angeles company. This current production unit is a redesign of part No. 107610, to which it is similar in both operation and performance. Operation, performance data, and applications are found in this bulletin in addition to schematic diagrams and dimensions. Notes and required problem statements complete the details.

• **Bendix Aviation Corporation . . .** Lawrence A. Hyland, a pioneer in radar detection of aircraft, has been elected to the post of Vice-President in Charge of Engineering for Bendix. Mr. Hyland joined Bendix in 1937 and has been a Vice-President since 1949.

• **Bendix Radio Division, Bendix Aviation Corporation . . .** A new 18-lb. V.H.F. receiver, now in production at Bendix Radio, provides 360 crystal-controlled channels. This receiver, the RA-18B, also provides 50-kc. channel spacing and is designed as a companion to the Bendix TA-18BB transmitter. The RA-18B operates in the frequency range of 118.0 to 135.9 mc. Selection of the desired frequency is accomplished by a control panel located in the ship's cockpit. The receiver operates from 27.5-volt d.c. or from 115-volt a.c. primary power source. Either type of power supply may be mounted as an integral part of the receiver.

• **The Bristol Aeroplane Company of Canada Ltd. . . .** Three Bristol Freighters, each powered by two Bristol Hercules 734 engines, are scheduled to be delivered to Trans-Canada Air Lines in September or October of this year. This delivery to T.C.A. is said to mark the first use in North America by a scheduled air line of aircraft designed solely for the purpose of carrying cargo. The Freighter has a total cargo capacity of 2,360 cu.ft., a range of more than 1,500 miles, a pay load of over 7 tons, and a cruising speed of 165 m.p.h. It has an overall length of 68 ft., 4 in., and a wing span of 108 ft.

• **Consolidated Vultee Aircraft Corporation . . .** Effective last February 15, the Convair plant at Pomona, Calif., became known as the Pomona Division. It was previously referred to as the Guided Missile Division.

THE FAIRCHILD-POWERED RYAN TARGET DRONE

The details of the J-44 turbojet engine (above), a product of the Fairchild Engine Division of Fairchild Engine and Airplane Corporation, as well as its use in Ryan Aeronautical Company's high-speed high-altitude pilotless target drone, the Q-2 Firebee, were announced on February 21. Described as the most powerful engine of its size yet developed in this country, the J-44 is in the 1,000-lb.-thrust power class, weighs 300 lbs., and measures 72 in. in length and 22 in. in diameter. It features an outer sheet-metal cowl of monocoque construction which forms both a pressure chamber and a frame structure connecting the two main-bearing supports.

THE NAVY'S NEW PRESSURE SUIT

This photograph shows the recently announced high-altitude pressure suit developed and engineered for the U.S. Navy by The B. F. Goodrich Company. This suit is designed to inflate automatically to survival pressures in case of failure of the plane's pressurization system. Carrying its own supply of oxygen and air under pressure, this suit is said to safeguard life at altitudes as high as 100,000 ft. According to company claims, this high-altitude pressure suit is the most flexible ever made.

• **Edo Corporation and The Cessna Aircraft Company . . .** The Cessna 180 has been officially approved to operate as a seaplane using Edo's Model 2425 floats. Under normal water conditions and aided by Edo's Para-lift flaps, the 180 takes off within 15 sec. Its rate of climb fully loaded is given as 940 ft. per min. with a service ceiling of 16,500 ft. As a seaplane, the 180 has a cruising speed in excess of 135 m.p.h.

• **General Electric Company . . .** U.S.A.F. approval has been granted to G-E's Aircraft Gas Turbine Division whereby only one out of every ten J-47 jet engines on the production lines must be strip-tested. This action, it is said, will result in savings of over 2,300,000 gals. of gasoline and 92,000 man-hours of work. . . . Two new departments, Guided Missiles and Aircraft Products, have been established within G-E's Aeronautic & Ordnance Systems Division. The Guided Missile Department will do research and development on guided-missiles programs for the Armed Services, while the Aircraft Products Department will be devoted to the development and production of aircraft armament systems and allied products. The Guided Missiles Department is located in the Schenectady plant, and the Aircraft Products Department is at the Johnson City, N.Y., plant.

• **G. M. Giannini & Company, Inc. . . .** An Angular Position Encoder, now available for general use, can be used for indicating angular shaft positions of 360° or less with a claimed accuracy of 0.1 per cent without use of gearing. The maximum shaft speed of 100 r.p.m. is presently possible. The unit can be connected directly to electromechanical printers or card-punch equipment to provide decimal digital data.

• **The B. F. Goodrich Company . . .** The development of a small electronically controlled pneumatic De-icer, about one-sixth the size of original ones, has been announced by the company. The De-icer, it is said, operates at three times the pressure of earlier types and completes the inflation-deflation cycle three times as fast. It consists of a network of small inflatable rubber tubes that expand sufficiently to crack off the ice but not enough to distort materially the shape of wing or tail surfaces. Goodrich engineers state that more than half a mile of this tubing, imbedded in thin panels of rubber cemented to leading edges of the wing and tail surfaces, is required to protect aircraft from ice.

• **Goodyear Tire & Rubber Company . . .** A new Piloted Aircraft Engineering Division, incorporating four long-standing departments, has been created at Goodyear Aircraft Corporation. These four departments are: Product Engineering, Project Engineering, Technical Service, and Administration.

• **Hamilton Standard Division, United Aircraft Corporation . . .** A wide-bladed propeller of hollow-steel construction supported internally by a steel core has been placed in limited production. This propeller, when mounted on a 5,500-hp. Pratt

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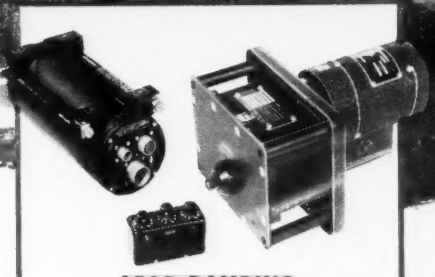

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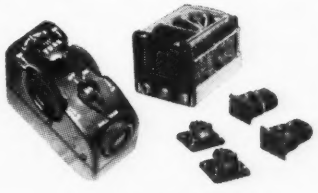

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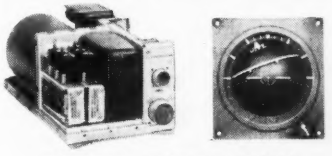

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LOCKHEED C-130, A TURBOPROP TRANSPORT

A scale model of Lockheed Aircraft Corporation's new turboprop-powered transport, designated the C-130, is shown in the accompanying photograph. The C-130 is designed to fly assault and support missions, carry troops and supplies to the front, and transport the wounded to the rear. It is powered by Allison turboprop engines that turn Curtiss-Wright three-bladed Turbolectric propellers. Its dimensions are: wing span, 132 ft.; length, 95 ft.; and height, 38 ft. The C-130 was designed by Lockheed in consultation with the Air Force and other branches of the armed forces. Prototypes of this transport are now under construction at Lockheed's Burbank plant. Production of the C-130 is planned for the Georgia Division.

& Whitney T-34 turboprop engine, is said to give more propulsive thrust for take-off than any other propeller-engine combination in a similar advanced stage of development. This propeller, which has the widest blades yet built, has been selected by the U.S. Navy for its R7V-2 turboprop version of the Lockheed Super Constellation transport, which will fly sometime this year. Designed initially for engines in the 5,000-hp. class, this propeller is the first of a line of propellers which, in various combinations of numbers of blades, can be adapted for engines of more than 9,000 hp. and airplane speeds of more than 500 m.p.h.

• **Lear, Incorporated . . .** At a recent Board of Directors meeting, Roy J. Benecchi, Assistant General Manager of Lear's Grand Rapids Division, was appointed an Assistant Secretary of the corporation.

• **Lockheed Aircraft Corporation . . .** A 5,000 cu.ft. refrigerator designed to deep freeze metal plane parts in order to keep them soft between two steps in fabrication was put into operation recently at Burbank. This $20,000 unit, which measures 40 by 12 by 11 ft., incorporates two openings: one is an outward-swinging door located at one side through which persons may pass; the other is an overhead door, measuring 34 by 4 ft., which is accessible to an overhead crane and sufficiently large to accommodate such pieces as the 32-ft.-long one-piece wing panels used on Super Constellation transports. . . . A $3,000,000 manufacturing building is being planned to provide additional space for assembly lines for transports and other large military aircraft at Burbank.

• **Minneapolis-Honeywell Regulator Company . . .** A highly intricate electrical "brain" that makes automatic flight possible from take-off to landing and which is known as an Automatic Master Sequence Selecter (AMSS) has been developed by Honeywell's aeronautical research engineers in cooperation with the U.S.A.F. Air Research and Development Command's Wright Air Development Center. This device, which is described as another step toward completely automatic flight, uses the punched-tape principle to program the functions of the autopilot and the airspeed control. The control media of this unit is a tape into which a prescribed flight plan (including taxiing, take-off, climb, etc.) has been punched by means of a special coding device developed by Honeywell for use with the AMSS. This punched tape is fed through the device, which has among its 1,000-plus parts and several miles of wiring 430 metal pins located in a sensing element. These pins move along the surface of the tape and upon locating the punches drop through them to make electrical contacts that in turn are converted into signals that operate the plane's controls. During a flight, a rigid time schedule is maintained by means of another Honeywell development, an Off-Schedule Distance (OSD) computer. The AMSS is so designed that the human pilot can take over manual control instantly if he should so desire.

• **North American Aviation, Inc. . . .** The first of North American's 25-ton carrier-based AJ-2 Navy bombers was test-flown on February 19. The AJ-2 is powered by two Pratt & Whitney R-2800 reciprocating

THUNDERJET MILESTONE

Alexander Kartveli, F.I.A.S. (left), Vice-President—Engineering of Republic Aviation Corporation and Designer of the F-84 Thunderjet, and Mundy I. Peale, A.M.I.A.S., President of Republic, stand before the 4,000th F-84 to be manufactured by the company. This particular plane was delivered to the U.S.A.F. However, the Thunderjet is in service with nine nations of the North Atlantic Treaty Organization.

South Wind Winterizes Continental "Packette" Engines

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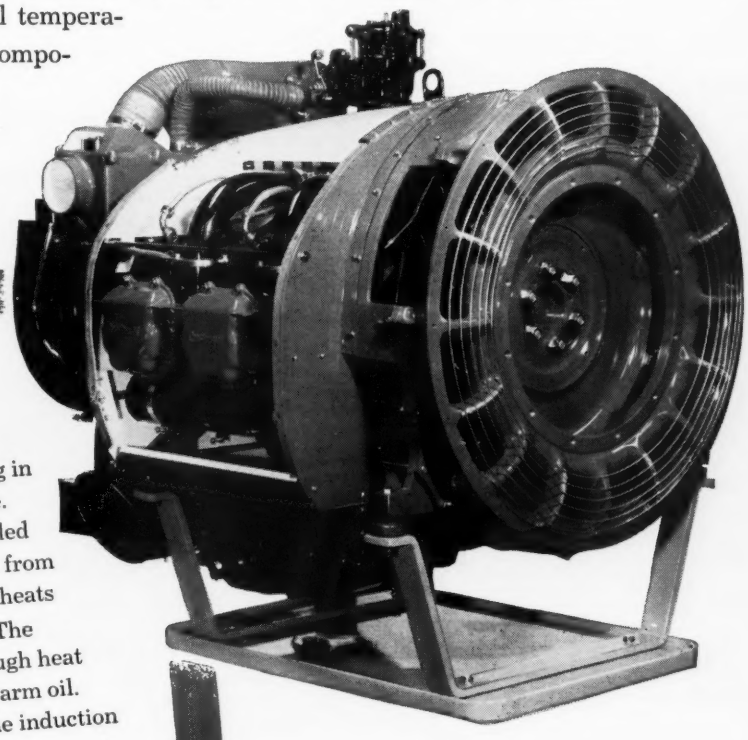
Meeting the stiffest requirements of cold-weather starting, the South Wind Heater can be used for pre-heating any engine in the Packette series. Makes starting easier, faster at all temperatures by flooding engine components, battery, crankcase and carburetor with warm heated air.



Duct carries hot air...

to crankcase through opening in block to heat inside of engine. Engine is completely shrouded to capture heat as it escapes from interior—this warm air pre-heats exterior surface of engine. The heater exhaust passes through heat exchanger in oil sump to warm oil. Hot air is diverted to engine induction system for starting phase.

There's a South Wind Heater for every Pre-Heating need

Do You Have A Heating Problem? South Wind is prepared to install pre-heating systems in every way to answer your requirements. Write today for the experienced counsel of South Wind field engineers about *any* problem in external or internal pre-heating. Wide range of South Wind Heaters includes 20,000—30,000—50,000—100,000—200,000 and 600,000 BTU/hr. capacities. Stewart-Warner Corporation, South Wind Division, Indianapolis, Ind.

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Do you have a control, or control system, problem? If so, we'd like to help you solve it. We've enlarged our research and development section so as to be of greater service to the aircraft industry. One project, now under way, is development of an even better control system for positioning an actuator by manual remote control or keeping two or more actuators in the desired relative positions. Another is widening the applicability of 26 volt DC control and control systems. A third is the perfecting of a 400 cycle control to operate with our 400 cycle, 110 volt motor and new actuators.

Our broad experience in the design and manufacture of electromechanical actuators, coupled with our expanded facilities for research and development work, enables us to give you more help. Let us develop a control system to exactly meet your application. Our recommendations will be based on an analysis of your needs.

A full statement of your requirements will permit us to study your problem and estimate our ability to solve it.

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engines and one Allison J-33 turbojet engine. The R-2800 engines are equipped with four-bladed Hamilton Standard propellers. The AJ-2 has a single large compartment to accommodate a crew of three and operates at speeds up to 450 m.p.h. Its wing span measures approximately 75 ft.; its length, over 65 ft.; and its height, 21 ft. The wings and vertical stabilizer of the AJ-2 fold to facilitate handling and storage below decks on carriers of the Midway class.

• **Northrop Aircraft, Inc.** . . . An agreement has been made whereby Northrop will purchase approximately 65 acres of land adjacent to the Hawthorne plant. The property is being purchased to provide "maximum efficiency for the company's flight operations from Hawthorne Municipal Airport and for possible future expansion." New facilities to be occupied by Northrop are now under construction at El Segundo and at Ontario (Calif.) International Airport.

• **The Parker Appliance Company** . . . District sales offices have been opened in Cleveland and Los Angeles. Other offices in a half-dozen other important industrial centers are expected to be established before long.

• **Seaboard & Western Airlines, Inc.** . . . Under a $350,000 equipment modernization program, Pratt & Whitney 1,450-hp. R2000-7m2 engines are being installed on the DC-4 aircraft of the company's Atlantic Division. These engines provide 100 hp. per engine more than those previously used and permit an increase in gross take-off weight of each aircraft from 70,700 lbs. to 73,000 lbs. . . .A total revenue lift of 36,598,933 ton-miles in commerical and military freight operations was flown across the Atlantic and Pacific Oceans during 1952 by Seaboard & Western's Airtrader fleet. The Airtrader fleet logged 6,940,634 revenue miles in 38,257 revenue flight hours. Seaboard & Western has ordered four all-freight Super Constellations, which are scheduled for delivery in 1954.

• **Solar Aircraft Company** . . . Small gas-turbine engines are to be assembled in the new factory building located adjacent to Solar's turbine test building in San Diego. This new assembly building with its 7,500 sq.ft. of manufacturing space and a 1,000-sq.ft. mezzanine was scheduled for completion on May 1.

• **Telecomputing Corporation** . . . The Teleducer, Type 24A, which automatically converts analog voltages into decimal digits with an accuracy of 0.1 per cent (1,000 counts full scale), has been announced. The Teleducer, it is said, operates upon demand, digitizes an input voltage, and holds the digital representation for a controllable period of time for purposes of display, recording, or any desired readout form. The digital output can be recorded by means of a punched card, an electric typewriter, magnetic tape, or punched tape. The instrument digitizes low voltage without d.c. amplification and high voltage by means of attenuators. A simple-bridge balancing circuit is used which is said not to hunt or oscillate and to require only 0.8 sec. or less to reach balance.

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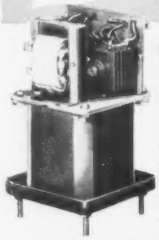

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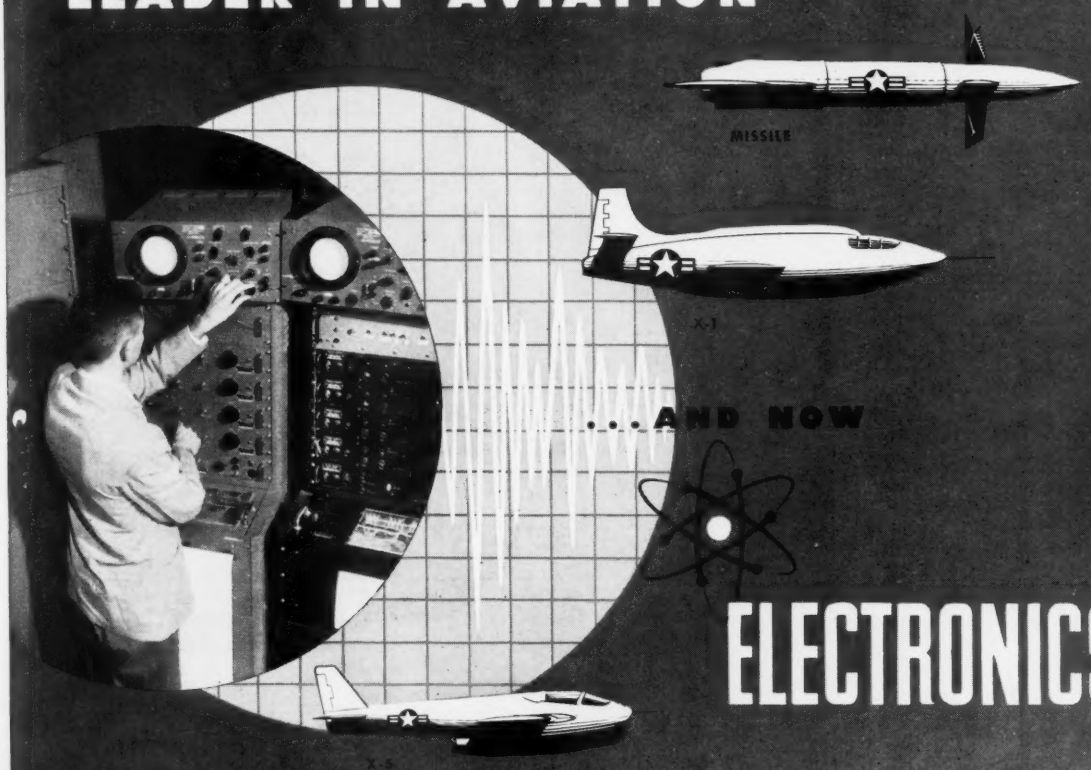

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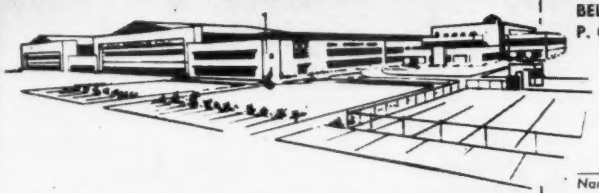

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• **Westinghouse Electric Corporation . . .** Plans for a new multimillion-dollar plant to produce atomic equipment have been announced. This new facility, to be located in Harmar Township near Pittsburgh, will be operated by a newly formed department in the Atomic Power Division known as the Atomic Equipment Department. At this plant, the company will "engineer, manufacture, and sell products that have been developed for atomic power plants." It is hoped that the new plant will be ready for occupancy by late fall of 1953.

I.A.S. Sections

Baltimore Section

J. Francis Maloney, *Secretary*

Dr. Wernher von Braun, noted rocket engineer who is Technical Director, Guided Missile Development Group, Redstone Arsenal, Huntsville, Ala., was the speaker at a meeting held jointly with the Associate Council and affiliates of the Engineer's Club of Baltimore. The meeting was convened at 8:30 p.m. on February 12 in the Maryland Casualty Company auditorium.

Boston Section

E. A. McBride, *Secretary*

Seventy-five persons attended the January 19 meeting, which was held at Massachusetts Institute of Technology in Cambridge. Chairman Ray L. Bisplinghoff presided.

The speaker of the evening was Dr. Jerome Hunsaker, Professor Emeritus and Lecturer in Aeronautical Engineering at Massachusetts Institute of Technology. The famed authority spent the past summer in Europe visiting aircraft companies and aeronautical research and military establishments. While in Turkey, he presented a paper before the Eighth International Congress for Theoretical and Applied Mechanics.

Dr. Hunsaker's subject for the meeting was "European Aeronautical Ideas," and he presented some enlightening aeronautical thoughts of Turkey, France, Switzerland, Holland, Germany, and Britain. A most interesting discussion period followed Dr. Hunsaker's talk.

Buffalo Section

George B. Melrose, Jr., *Secretary*

An attentive audience of about 200 persons listened to Dr. Walter R. Dornberger, Missile Design Consultant to the Vice-President—Engineering, Bell Aircraft Corporation, deliver a lecture on "Rockets, Satellites, and Space Ships" before the Buffalo Section on January 14. Chairman Al Krivetsky presided at the meeting.

The address covered a great many of the aspects of rocket propulsion, upper atmosphere physics, and rocket ship design. Dr. Dornberger noted that the most desirable means of attaining space flight to a planet was through use of a Space-Ship System. He pointed out that design of a 5- or 6-stage space ship, to attain the escape velocity of 7 miles per sec., would lead to a ship of overwhelming size and weight. He stated that an attempt at a direct earth-planet flight will never bring about the conquest of space.

Dr. Dornberger then described the concept of a Space-Ship System for flight to a heavenly body. The four components of such a system are as follows: (1) the three-stage shuttle rocket, to transport men and material to a 1,075-mile-high, 4.5-m.p.s. satellite orbit; (2) the satellite space station, built in the orbit and used as a base for space ship operation; (3) the space taxis for ferrying flights between the satellite and shuttle rockets; and, finally (4) the real space ships, for accomplishing the last step of space travel to a planet. The speaker discussed the space station problems of vulnerability, balance, temperature, breathing-air supply, meteorite collision, producing operating power, and possible methods of solution. He noted that practical needs will determine the configuration of a space ship since streamlining is unnecessary in outer space. Cabins, tanks, combustion chambers, etc., might therefore be hung like balls on a light-weight aluminum-girder Christmas-tree frame.

Dr. Dornberger briefly described a trip to Mars. The optimum flight path consists of a 260-day elliptical journey to the planet. The overall round trip would require about $2^1/_2$ years. Assuming that a fleet of ten space ships would be necessary, the entire venture was estimated to cost approximately 10–12 billion dollars—not excessive when compared to defense and war costs.

The nation that will be first in space with an artificial satellite will govern the world, Dr. Dornberger emphasized. The time when daring conquerors seek to discover new continents for the human race will return, backed by the urgent wish of the people of the world.

Chicago Section

Charles L. Bonnette, *Secretary*

On February 5, 53 members and guests of the Chicago Section held a meeting at the Museum of Science and Industry. A fine dinner was served in the Museum's Dining Hall.

At 8:00 p.m., the meeting was called to order by Dr. H. L. Hull, Chairman. The speaker of the evening, Otto E. Kirchner, Director of Operational Engineering, American Airlines, Inc., presented the Sixteenth Wright Brothers Lecture, "Technical Trends in Air Transport." This paper was originally presented by William Littlewood, Vice-President of Engineering, American Airlines, in Washington, D.C., on December 17, 1952.

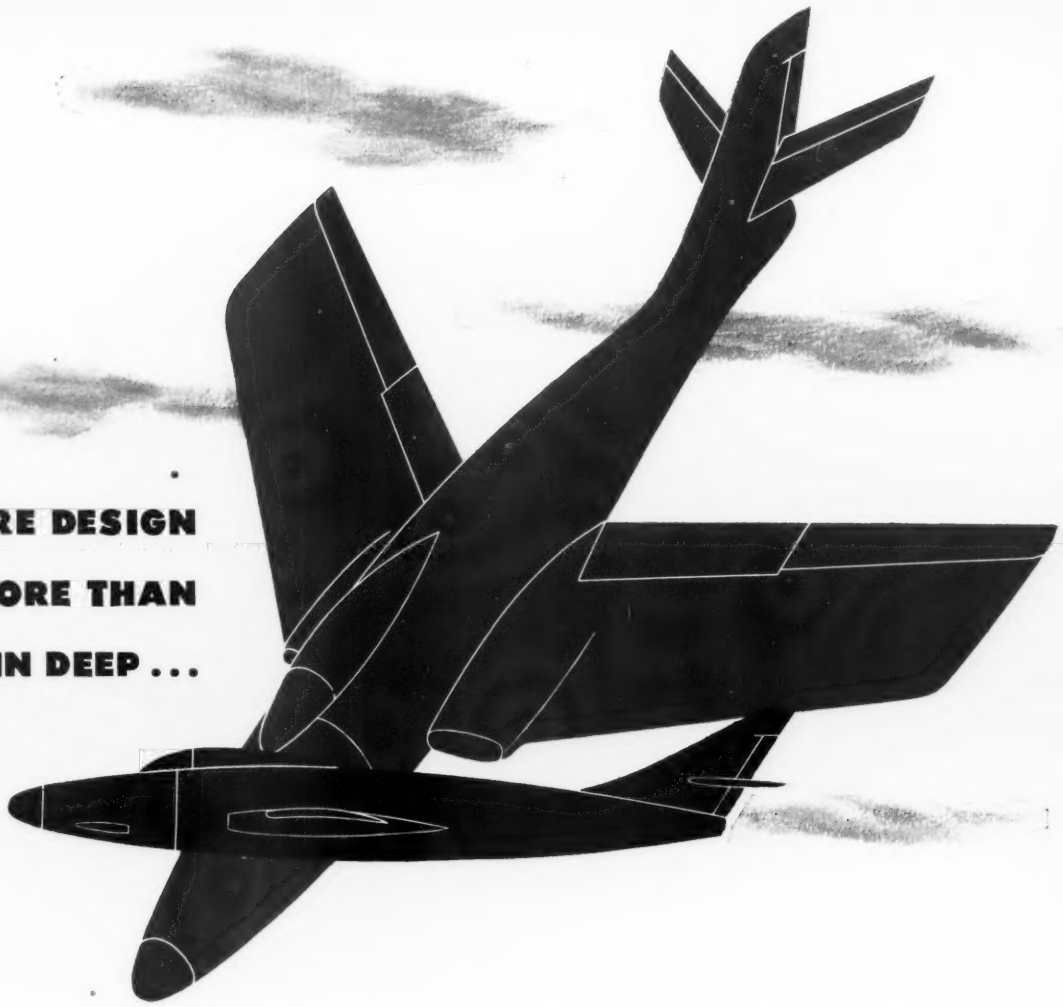
Mr. Kirchner's address was illustrated by a group of slides and interestingly highlighted with data indicating trends of American air lines from 1938 to 1953. He outlined some of the critical design features that exist in the construction of the modern air liner and which affect the safety of the passengers. Progress in the design of turbojet transports, their advantages and shortcomings, together with a description of the jet aircraft in use today, was presented in a most interesting manner. An actively supported question and answer session followed the lecture.

Cleveland-Akron Section

R. E. Bolz
Secretary-Treasurer

The February 17 dinner meeting took place at the University Club of Akron, Ohio. There were 130 present at the dinner. The social hour before the meeting was sponsored by The General Tire & Rubber Company, of Akron. The main program began with a short talk by Charles Burke, Assistant to the President of General Tire & Rubber, who discussed the company activities in the aviation field, concentrating on the activity at the Aerojet Division on the West Coast.

The main speaker of the evening was to have been Rear Adm. P. E. Pihl, U.S.N., Assistant Chief for Research and Development, the Bureau of Aero-



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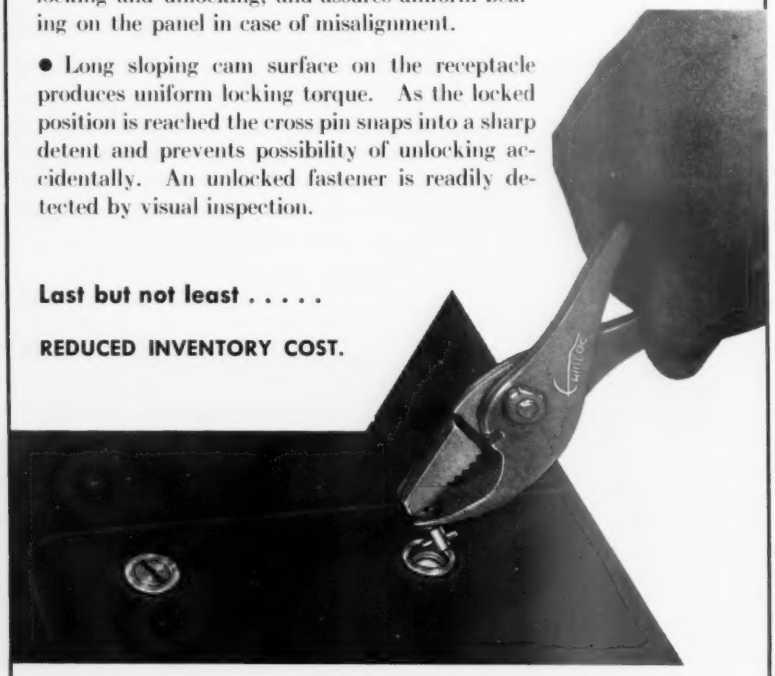

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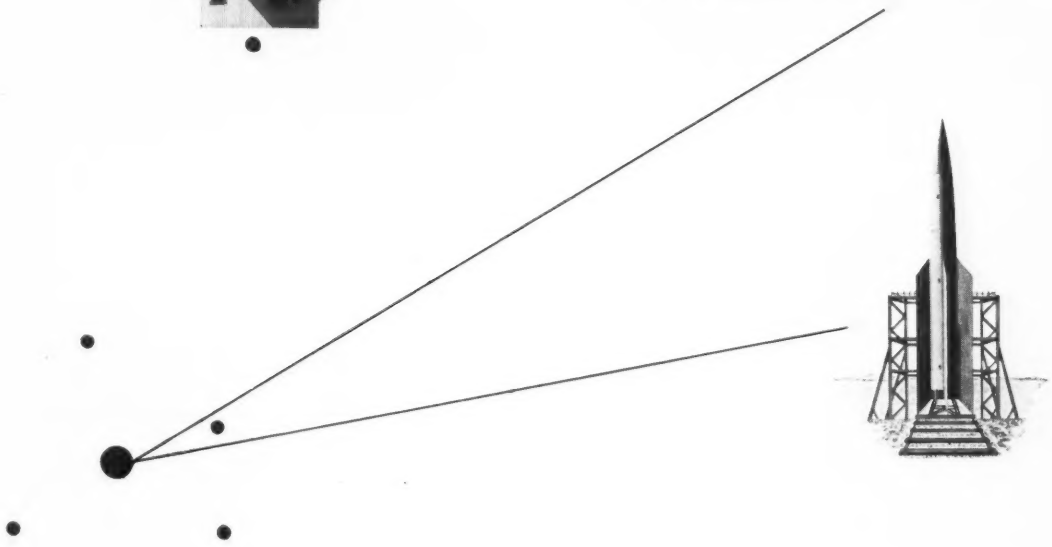
nautics. Admiral Pihl, however, was hospitalized, and Capt. Joseph N. Murphy, Executive Director of Research and Development, BuAer, ably presented the main talk. The title of the paper was "Navy Aviation in the Supersonic and Atomic Age." Captain Murphy discussed major developments in Navy aviation during the past few years with emphasis on three topics: (1) high-speed sea planes, (2) airships for Navy use, and (3) the concept of the canted-deck aircraft carrier.

The advantages of high-speed sea planes over land-based craft were stressed by Captain Murphy. He pointed out that water inlets offer unlimited opportunities for basing aircraft and that these inlets are indestructible and have a low cost. If a sea plane can be designed for high-speed flight and for taking off and landing on the ocean surface, the advantages in time of war would be unlimited. Naval research is emphasizing improvement in hydrodynamic designs and the use of water skis and planing-tail hulls. The troublesome features of fighter sea planes are the beaching and launching operations; here, the possibility arises for the use of water skis in combination with beaching wheels. Captain Murphy indicated the future use of water-based aircraft with good aeronautical design is a real possibility.

The next part of the talk concerned the use of airships in the Navy. The speaker touched upon the subject of submarine-launched guided missiles with atomic war heads and emphasized the necessity of low-speed submarine searchers capable of carrying a very large quantity of submarine detection equipment, as well as armament. Here, the airship seems to have a vital place, and significant new airship designs are in progress.

The third topic of the talk concerned the advantages of the canted-deck aircraft carrier. This idea of aircraft landing diagonally across the deck of an aircraft carrier was introduced by the British in 1951 and offers a solution to many of the problems of carrier landings. The canted deck allows the airplane to land on the deck of a carrier without the necessity of a barricade between it and the parked aircraft at the end of the landing strip and with 70 per cent of full power. Under this arrangement, if the pilot misses the arresting wires or bounces on the canted deck, he merely gives the engine full power and comes around for another try at the landing. At the present time, with the conventional carrier, such a maneuver would cause the airplane to crash against the barricade or into the group of parked aircraft.

The tests on the Midway resulted in enthusiastic success for the canted deck. This new method turned out to have a



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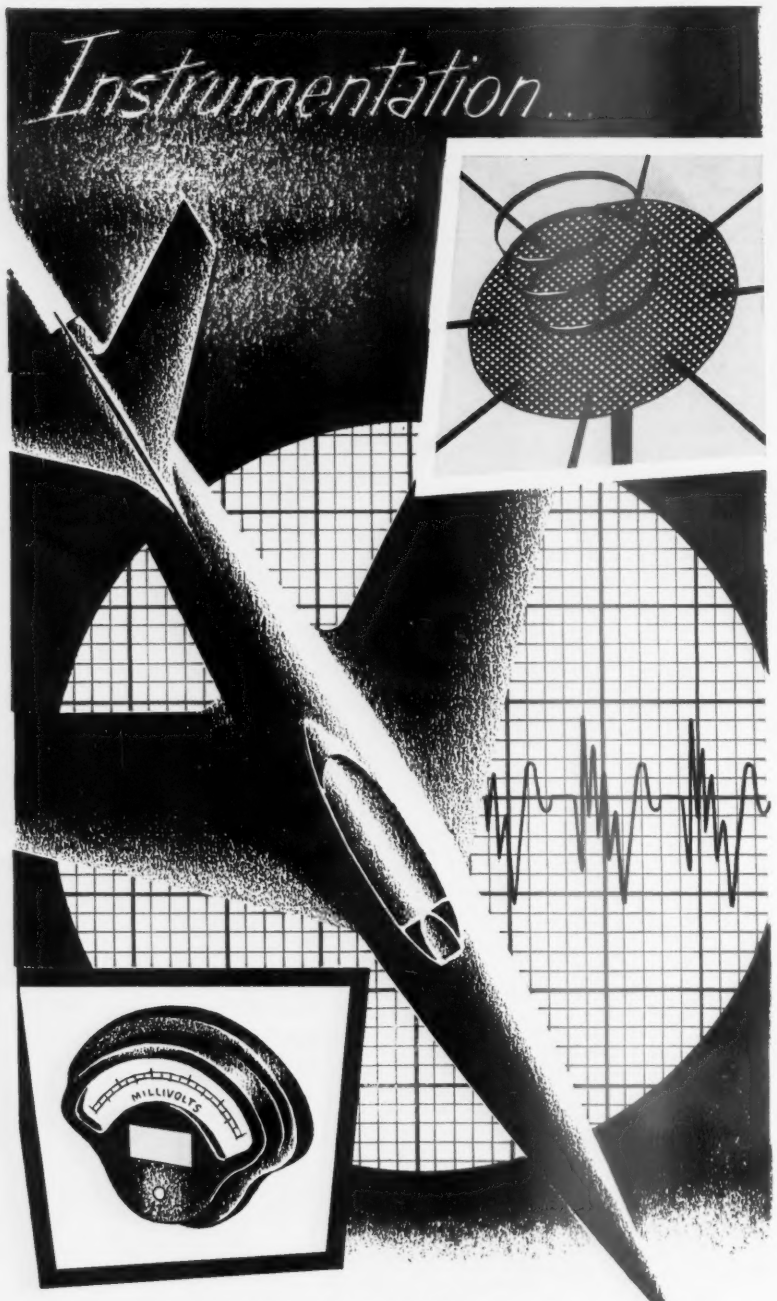

tremendous psychological effect on the pilot who, when not faced with a possible crash into either the barricade or parked planes, was much more successful in his landings. The use of the canted deck also allows a smaller number of arresting wires, increases the speed with which aircraft can be cleared from the landing strip, and results in a lower strength requirement of the landing gear.

After an active question period following the talk, the meeting was adjourned at about 10:30 p.m.

Los Angeles Section

Harold S. Fischer, *Secretary*

"Automatic Hovering Control for Helicopters" was the subject of a Specialist Meeting held on February 12 at the I.A.S. building in Los Angeles. The speaker was Edward N. Noneman, Project Engineer of the J. B. Rea Company, Inc. Mr. Noneman described the characteristics of a hovering control that was designed for use with several existing helicopters and autopilots. A simple "rope-and-weight" ground-contact system, chosen in the design to sense distance from the ground and drift, met the stringent hovering requirements. Nyquist plots and root-locus diagrams were shown to demonstrate the stability of the helicopter itself, as well as the overall characteristics of the aircraft, plus its automatic hovering control system.

The February 19 dinner meeting was featured by presentations of the "Piloting and Engineering Problems Associated with the 1952 World's Aircraft Speed Record Trials." Captain J. Slade Nash, Air Force Project Pilot at the Air Force Flight Test Center, Edwards A.F.B., Calif., described his experiences in setting a new world's speed record of 698.505 m.p.h. in an Air Force F-86D airplane, and George Mellinger, Chief of Engineering-Flight Test Department, North American Aviation, Inc., told of the engineering aspects of planning and conducting the record flight. Mr. Mellinger gave some interesting background of the history of record flights and also described the technical aspects, instrumentation, data reduction techniques, and operational problems of the flights. Captain Nash, whose abilities as a speaker proved comparable to his piloting prowess, gave an insight into the piloting techniques and problems of this specialized type of flight. As an added feature, the audience of about 400 received copies of a brochure, compiled by the Historical Associates of the I.A.S. here, depicting the history of the world's aircraft speed records.

Another Specialist Meeting was held on February 26, at which H. N. Riise,

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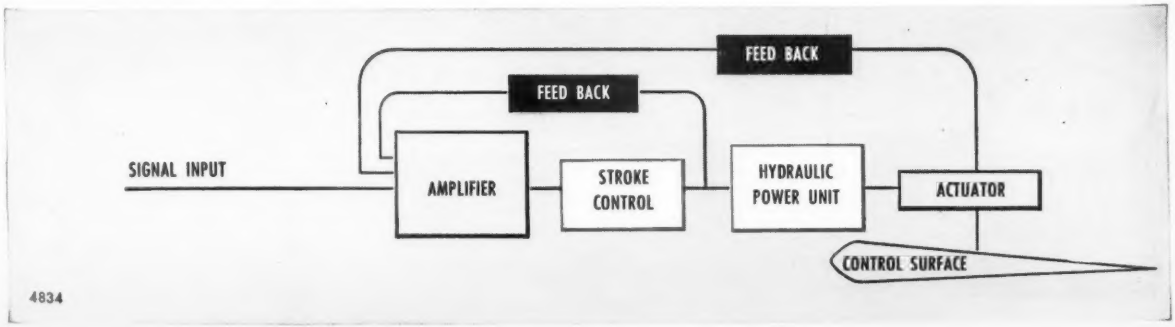

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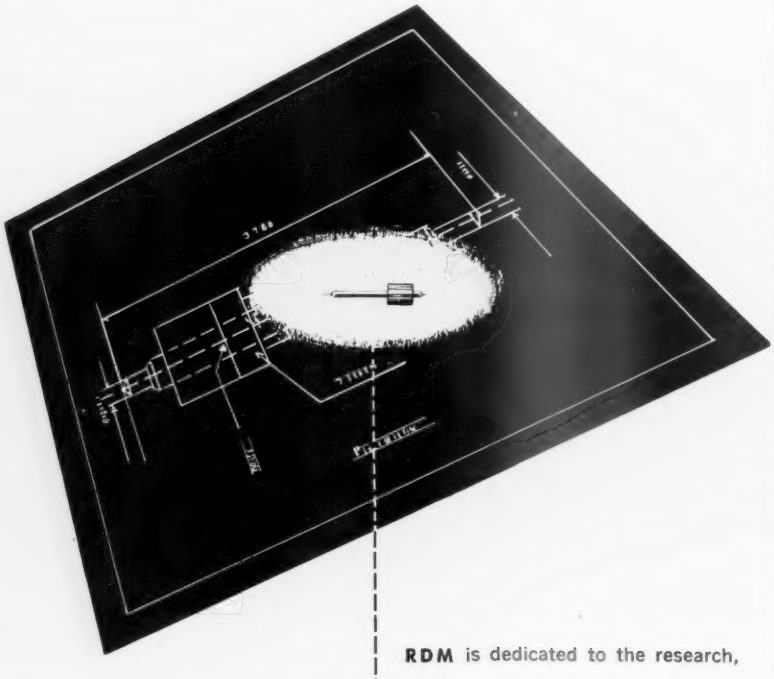

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Research Engineer of the Jet Propulsion Laboratory of California Institute of Technology, discussed the "Development of Flexible Nozzle Contours for the J.P.L. 20-inch Supersonic Wind Tunnel." The nozzle, now in operation at J.P.L., has been under development for several years and provides a continuous range of Mach Number for testing in uniform flow, as well as the option of arbitrary pressure distribution.

Montreal Section

B. J. Kaganov, *Secretary*

The February 9 meeting was opened by Chairman E. H. Higgins, who immediately called upon A. E. Ades, Vice-Chairman, to introduce the guest speaker.

The Montreal Section was fortunate to have as its guest speaker Jerome Lederer, Director of Flight Safety Foundation, Inc., who spoke on the subject "Flight Safety."

Reviewing statistics on the growth of air transportation and the number and type of accidents which have occurred, the speaker pointed out the importance of passenger and crew survival after an accident and confined his lecture to that aspect of the subject. Mr. Lederer referred to actual cases where occupants survived the initial crash but were subsequently unable to get out of the airplane and were either suffocated or burned to death. He emphasized the responsibility of designers in avoiding such fatalities by more careful attention to cabin arrangements and the many apparently minor details that greatly affect the chances of survival. Among such items that Mr. Lederer considered important are emergency exits and doors which can be opened by a single motion of the hand, passenger seats that do not deform in such a way as to injure the passengers or block the aisles, and prevention of heavy objects from tearing loose and injuring the occupants.

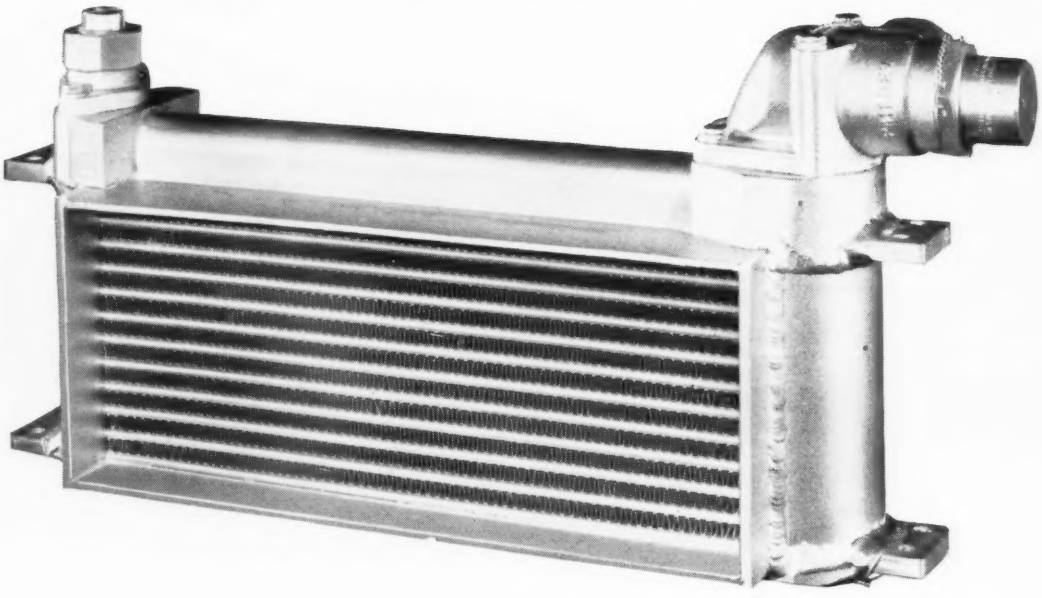
The speaker also pointed out the importance of protecting the cabin attendants who are trained to direct evacuation of passengers after a crash.

On the subject of rearward- versus forward-facing seats, the speaker said that, while he had previously favored rearward-facing seats, it now appeared to him that both had definite advantages and drawbacks and that more experience was needed before drawing definite conclusions.

At the close of his talk, Mr. Lederer showed two interesting films taken during practice evacuations after a simulated emergency landing and a ditching at sea.

A lively question and answer period followed, and at the conclusion Mr. Lederer was thanked by Carl Larsson, of Canadair Limited.

A modern oil cooler for modern aircraft



Long experience in the development of heat-exchanging equipment for a variety of purposes has made it possible for Harrison to design an aluminum plate-type oil cooler that meets the specific needs of modern aircraft, both commercial and military.

This oil cooler is *light* and *compact*—can be fitted into almost any available space. It is *ruggedly built*—can withstand pressures up to 400 psi. It is *efficient*—a thermostatically controlled valve automatically by-passes oil until a pre-determined temperature is reached. And it is Harrison quality, through and through.

Moreover, this modern aircraft oil cooler may be used for a variety of jobs—to cool the fluid in hydraulic systems, to cool helicopter engine and gearbox oil, to cool turbojet and turboprop compressor bearings and turbine bearing lube oil. Aircraft engine and airframe manufacturers are urged to write for specific performance data.

HARRISON RADIATOR DIVISION

GENERAL MOTORS CORPORATION, LOCKPORT, NEW YORK

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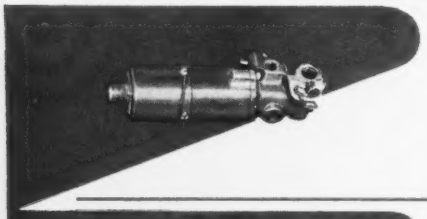

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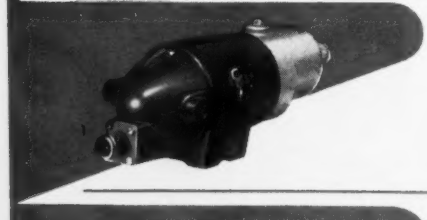

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New York Section

Charles Tilgner, Jr.
Secretary-Treasurer

Acting Chairman F. K. Teichmann opened the March 3 meeting and introduced Harry A. Jackson, of the Battelle Memorial Institute. Mr. Jackson discussed briefly the properties of many high-temperature metals. Besides mechanical properties, he also touched on the subjects of high-temperature fatigue, service tests, thermal fatigue, and some of the effects of changing chemical properties.

C. R. Mayne, of the International Nickel Company, was introduced as moderator, and he in turn introduced the panel, consisting of Mr. Dyrkacz, of Alleghany Ludlum Steel Company; Mr. Hanink, of Wright Aeronautical Corporation Division, Curtiss-Wright Corporation; Mr. Luster, of Rem Cru Titanium Company; Mr. Payson, of Crucible Steel Company; and Mr. Goller, of Armco Steel Company.

As a result of several questions from the floor, a spirited discussion followed. For more than 1 hour, questions and answers were bandied back and forth between the panel and the audience. It was unfortunate that due to the adverse weather, there were not more people to enjoy this inspiring program.

San Diego Section

E. R. Hinz, *Secretary*

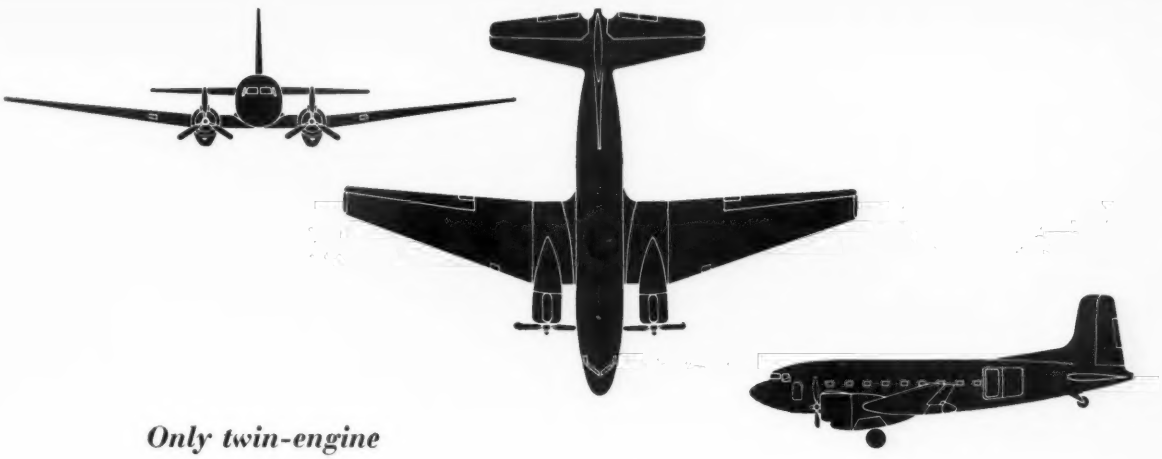
The big event for the San Diego Section during February was the reopening of the Institute of the Aeronautical Sciences building to Section activities. For the past $2\frac{1}{2}$ years, the building located adjacent to San Diego Bay and Lindbergh Field has been leased to a local aircraft company for urgent defense work. Upon completion of the defense contract, the building was reconditioned and returned to the Institute.

The first dinner meeting to be held in the building after its reopening took place on February 26. Approximately 100 members and guests attended to hear Benny Howard, noted aviation consultant, speak on "The Attainment of Greater Safety." Benny Howard's forthright presentation of means to improve flying safety was enthusiastically received by the audience. Previously prepared comments on Mr. Howard's paper by K. E. Ward, L. Bordelon, and F. D. Applegate, of Convair, were read, and the speaker commented on them in turn.

Twin Cities Section

Wesley J. Fisher, *Secretary*

On January 22, a meeting of the Twin Cities Section was held in the Engineer-



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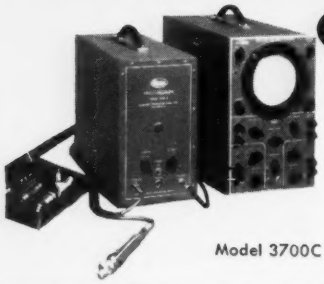

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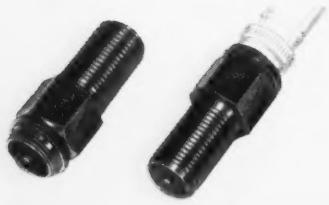

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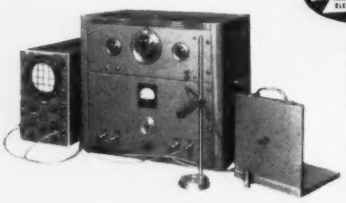

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ing Auditorium of the University of Minnesota. After a business meeting, at which officers for the year were elected, a program was presented by Lt. Comdr. John C. Mitchell, U.S.N., Training Officer, Naval Air Station, Minneapolis, entitled "Operational Aviation Safety."

The officers elected for 1953 are: Chairman, Alfred E. Cronk; Vice-Chairman, David L. Mellen; Secretary, Wesley J. Fisher; and Treasurer, Robert A. Hoel.

Washington Section

J. H. Sidebottom, *Chairman*

At a regular meeting on February 3, four distinguished members of the aviation fraternity spoke on their particular interests in the present turbotransport development program. Fred B. Lee, Deputy Administrator for the Civil Aeronautics Administration, served as Honorary Chairman and introduced the first speaker, Adm. DeWitt C. Ramsey, U.S.N. (Ret.), President of Aircraft Industries Association.

Admiral Ramsey discussed the history of the industry's position on various Congressional proposals for advancing turbotransport development and pointed to the fact that the manufacturers' advances in military designs over the past 10 years would be significantly profitable in the ultimate U.S. turbine-powered transports for civil use. He stressed the continuing interest of the industry in Public Law 867 and stated that some benefits may still be derived from this legislation if money is appropriated for accelerated testing of new designs in the near future. He assured the audience that the private manufacturers' attention to turbine-powered civil types was not lagging and that private funds already devoted to the development in several of the manufacturers' plants would undoubtedly pay dividends to the air-line operators in the near future. In quoting one manufacturer, Admiral Ramsey stated that "we would not wish to bring out a jet transport, the cost of operation of which was higher than contemporary piston-type transports." Admiral Ramsey concluded his presentation with an outline of some technical problems, particularly those related to the noise dilemma that will certainly be a vital factor in determining the rate of progress in jet aircraft.

Brigadier General Milton Arnold, U.S.A.F. (Ret.), Vice-President—Operations and Engineering, Air Transport Association, spoke on behalf of the air-line operators on the economics of jet-transport operations as contrasted to present piston-engine operations. He stressed the fact that before the air lines can incorporate turbine-powered

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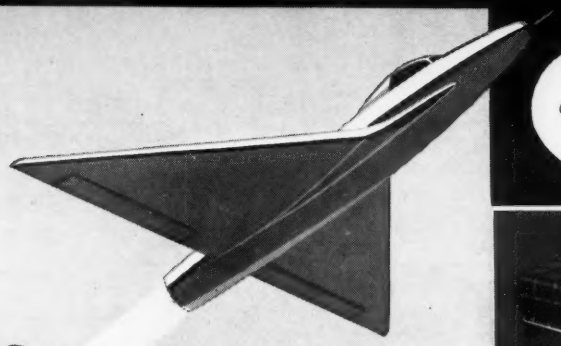
aircraft into their fleets, they must be assured that such action will not involve a backward step in safety; that such aircraft will be capable of carrying 70 to 80 passengers without penalties on range; and that operating costs per ton-mile will be equal to, or less than, current transports. General Arnold also underlined the problems of jet-engine reliability and the cost of development for a U.S. jet-transport prototype, which is now estimated at about $30,000,000. He concluded his remarks by stating that, on the basis of present estimated costs, the air lines cannot operate jet transports at the present fare levels. The basic problem is to obtain a turbine-powered aircraft that can pay its own way, and only through experience by military and commercial operators currently operating turbine-powered equipment will we be able to determine the appropriate time for introduction of this vehicle into United States domestic and international operation.

The interest of the Military Air Transport Service in the turbine-transport field was discussed by Lt. Gen. Joseph Smith, Commander of M.A.T.S., who outlined the contributions that the Navy and Air Force have made in strongly supporting turboprop development in the R7V, R3Y, C-130, T-29, and C-124, in addition to several contracts for studies of jet-type transports to be built around engines available within the next 5 to 10 years. General Smith indicated that, from the military viewpoint, turboprop transports would be used on long-range cargo operations and that such aircraft had a definite place in military service. On the other hand, he stated that the straight jet transport is ideally suited to the mission of rapid transportation of high-priority passengers, medical patients, and other critical cargo. He stated that there was no reason why the military and civil requirements for jet transports cannot be comparable and that there is a critical need for maximum interchangeability to provide optimum utility in the event of emergency. General Smith stated that testing of new equipment and systems is provided for in the M.A.T.S. charter, and, if M.A.T.S. were permitted to do the testing, it could relieve the air lines and manufacturers of a heavy burden. In speaking of solving the present problem of making the jet-transport airplane a real thing, General Smith said that "an air transportation system is comprised of aircraft, airfields, adequate weather and communications support: navigation and air traffic control facilities; foolproof maintenance standards and procedures; a sound logistics system; rules and regulations; and, above all, plenty of horse sense." He stressed in the closing sentences of his presentation that the industry "must all think in terms of a jet transport system." The success of jet transportation, he finished, lies in the solution of the problems associated with all factors that make up the jet air-transportation system.

Honorary Chairman Lee concluded the presentations with a status report of what the U.S. Government, particularly the C.A.A., has done and is doing in the field of civil turbine-jet transport development. He outlined the various groups within the Government which have been concerned with the problem of developing new jet transports since early 1945 and mentioned the fact that at present a special turbine-transport evaluation group is engaged in reviewing the present programs to affect uniformity in handling of type certification: to develop basic criteria and policies of type certification and operations; to carry on the activities assigned for testing under Public Law 867; and to provide a central source of information on turbine-jet transport development. Mr. Lee also compared the British development with the U.S. program as an extremely important key to problems that the C.A.A. will face in the coming 5 to 10 years. He cited the possibility that testing under Public Law 867 might allow us to make substantial progress in avoiding difficulties of a technical nature in the operation of civil transports that were introduced immediately



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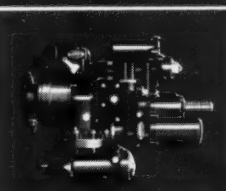
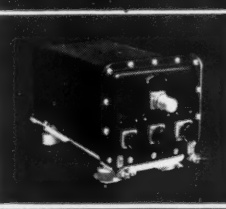


FUEL METERING UNIT Electrically controlled, this unit meters fuel to the engine in accord with signals from the electronic control.



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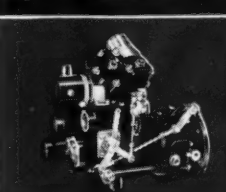
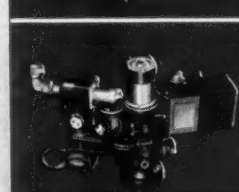
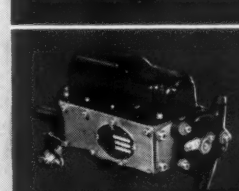


MAIN FUEL CONTROL The control illustrated includes a governor which holds the engine at a selected speed regardless of altitude.



AFTERBURNER FUEL CONTROL Graduates the afterburner thrust by selecting fuel flow in various proportions to mass air flow through the engine.



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after World War II. Among the technical problems that must be faced, Mr. Lee cited Mach Number limitations, explosive decompression, navigation and communication problems, aircraft deceleration, and the inherently greater noise level.

The meeting was concluded with a spirited discussion of certain questions involving some of the technical problems to be overcome and a brief résumé by several Washington Section members of advances being made by industry and Government groups in the jet field.

We were fortunate to have as our guests for the evening four members of the British Air Registration Board, which is headed by R. E. Hardingham. Mr. Hardingham concluded the program with a brief review of British experiences in solving some of the problems that the speakers had mentioned in their talks. He stated, for example, that the noise problem accompanying the introduction of the Comet operations at London Airport had practically vanished once the population came to accept the noise as merely a different, but not necessarily more disagreeable, airport distraction.

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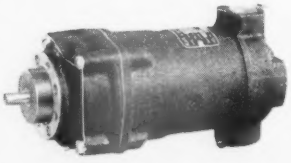

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Student Branches

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Kenneth O'Connor, *Secretary*

A Branch meeting was held on March 4 for the purpose of appointing committees and arranging field trips. Erich Bold, Bob Kassl, and Fred Bodnarchuk were appointed to the Membership Committee; Richard Wessner, Felix Curasi, and Joseph Ciecone were appointed to the Meetings and Papers Committee. The purpose of this committee is to select the best lecture presented by a fifth termer this semester.

Two motion pictures were shown, *The ABC of G* and *Speed Nut Savings Factor*. The latter film showed the variety of uses to which the Speed Nut could be applied. *The ABC of G* illustrated the gravitational forces that act on the pilot and plane while at high speeds or performing sharp maneuvers.

Agricultural and Mechanical College of Texas

Ray M. Custer, *Secretary*

Chairman Arthur Goldberg opened the February 10 meeting with a discussion of current business. The resignation of Theodore Nark as Secretary was accepted, and Ray M. Custer was elected to this office to serve in his stead.

The final details of the I.A.S. Texas Section's First Annual Student Paper Competition were made available to the Student Members. Chairman Goldberg urged that everyone seriously consider entering a paper in a preliminary contest. Faculty members of the Aeronautical Engineering Department have expressed the desire to cooperate with those interested in choosing suitable topics for such papers.

The Catholic University of America

William G. Elsen, *Secretary*

The featured speaker at the March 4 meeting was W. R. Witt, of the Naval Ordnance Laboratory.

The title of Mr. Witt's talk was "Reynolds Number Transition Studies in Free Flight," and the change of boundary layer from laminar to turbulent in cone-cylinder supersonic projectiles was explained. By means of a firing range and shadow pictures of the projectiles taken during flight, the point of boundary-layer transition was determined.

The purpose of this study, Mr. Witt explained, is to determine whether the point of transition for various projectile shapes and finishes fired under varying Reynolds Number can be computed in advance. Pictures of some of the

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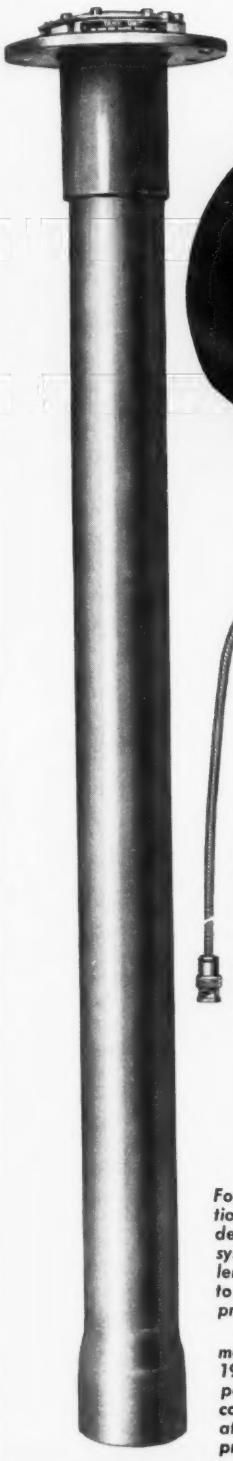

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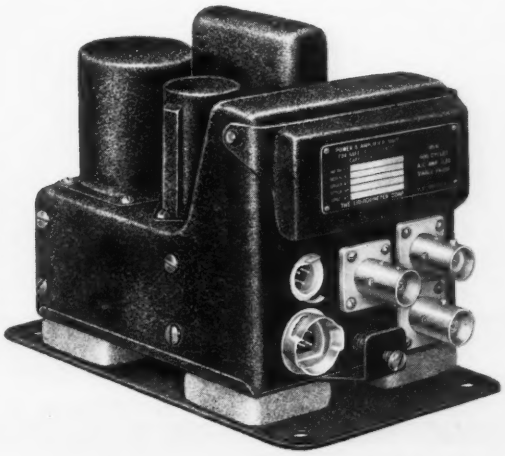

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projectiles in flight and some graphic results were shown to the members.

Chairman Earl Erickson presided at the meeting of 10 members and several guests.

Parks College of Aeronautical Technology

Lawrence J. Long, *Secretary*

The meeting of February 12 was opened by Vice-Chairman Paul T. Sumida with 60 persons present. Plans were made to hold a preliminary contest so that two student papers could be selected for entry in the Texas Section's First Annual Student Paper Competition.

It was announced that Louis A. Perrin and Paul T. Sumida will receive the Student Scholastic Awards for 1952.

After the regular business was finished, Vice-Chairman Sumida introduced Karl Faymon, Assistant Professor in the Aeronautical Engineering Department, who gave an excellent lecture and demonstration on "Water Tables."

Movies from McDonnell Aircraft Corporation were then shown.

The Pennsylvania State College

Frank A. Leader, *Secretary*

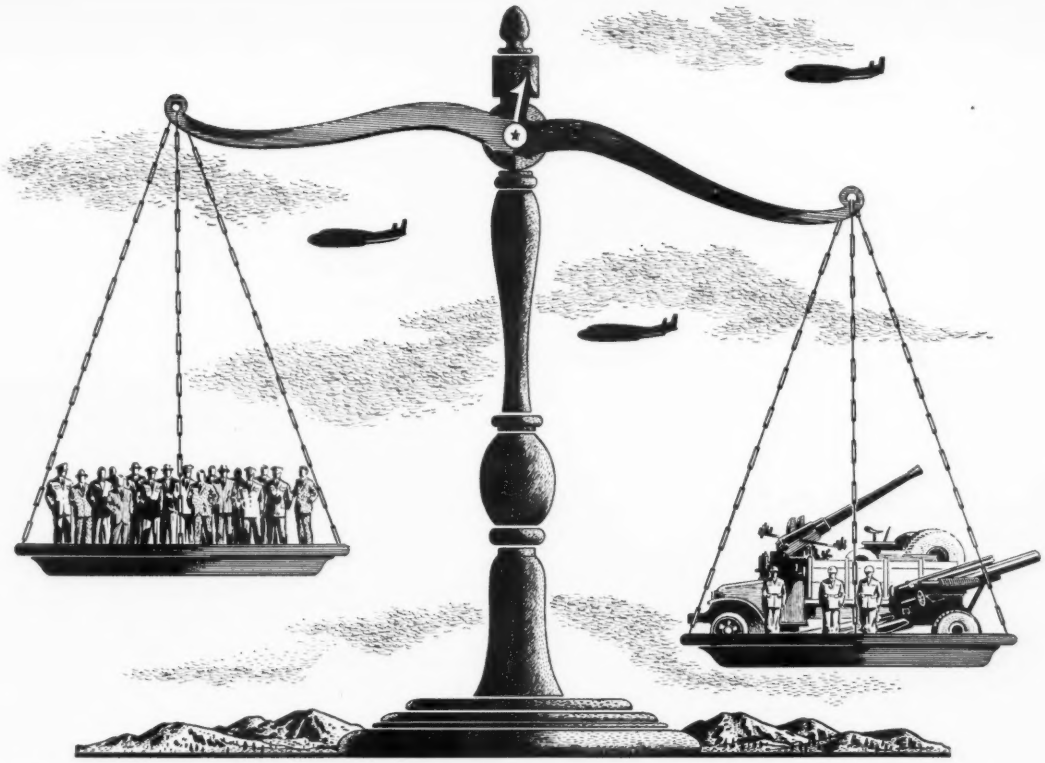
A regularly scheduled meeting was held on February 5 on the Penn State campus with 35 members attending.

Chairman Max Schuster presented a letter inviting participants to the first North-Eastern Conference of the Student Branches of the I.A.S. to be held at Rensselaer Polytechnic Institute, Troy, N.Y., on April 10 and 11, 1953.

Walter Hatcher, from Piasecki Helicopter Corporation, was then introduced. He started by showing an untitled film put out by his firm on the different models and their flight characteristics. After the film was shown, he gave a brief talk on "Commercial and Military Aspects of Transport Helicopters," in which he discussed the many uses being made of helicopters today such as rescue, mail carrying, surveying, etc. In pointing out the advantages of the helicopter, he showed the tremendous possibilities for its further utilization in the near future.

▶ Ernest C. Laudeman was the only aeronautical engineer to graduate in January. He has secured employment in the Flight Test Department of the McDonnell Aircraft Company.

▶ The second joint meeting of The Pennsylvania State College Student Branch of the I.A.S. with A.S.M.E. and S.A.E. for this year was held at The Pennsylvania State College on February 17, with John Hahn, President of S.A.E., presiding.



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"Cost per ton-mile" is what military planners watch in everything that concerns air transport to our Armed Forces. And rightly! But let's be careful what we mean by "ton-mile cost." It's got to be *loaded* cost.

Men can march on and off *any* plane. The big problem is equipment . . . tanks, trucks, bulldozers, massive pieces. Operating cost for such shipments *must* include loading and unloading . . . with all the attendant factors. If equipment has to be knocked down and crated, then uncrated and reassembled at destination . . . that's cost. Man-hours for handling, expensive machinery for carting, hoisting, stowing . . . that's cost. And longer turnaround time for these cumbersome operations is also cost . . . idle aircraft eating up dollars.

Reckoned completely, with all these factors, ton-mile cost for the Fairchild Packet C-119 is the lowest ever achieved in air history! Tanks and trucks roll up its ramp as easily as men march in. Bulk cargo goes "as is." Turnaround time is the fastest ever. And in addition, this rugged "Flying Boxcar" is the most versatile in air transport. No other aircraft has remotely approached its successful score for air drops of men and materiel . . . 10 tons dropped from a single C-119!

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To military men all over the world, the TWIN BOOM of the Fairchild Packet means "big stuff" ready to land . . . tons of bulky supplies or squads of troops ready to pour down the ramp and go into action at the lowest total cost in money and time. That's lowest *total* cost . . . *ton-mile cost loaded, and unloaded.*

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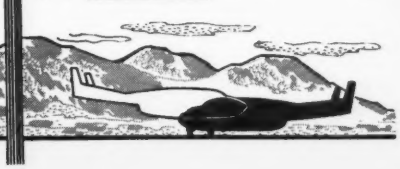

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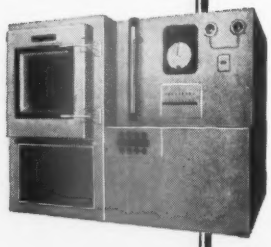

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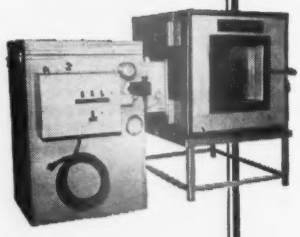

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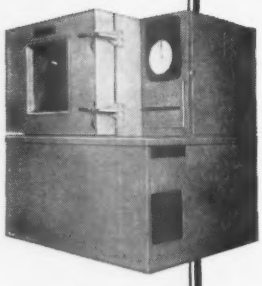

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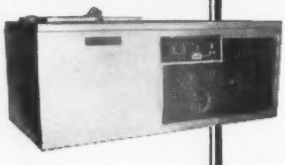

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J. E. Barfoot, from Boeing Airplane Company, was the speaker of the evening and presented a talk on "Design Aspects of Modern Air Transports." Mr. Barfoot showed a group of slides which gave graphic comparisons of the reciprocating, turboprop, turbojet, ramjet, and rocket engines in their different operational functions such as speed, fuel economy, cost per ton-mile, etc. On the basis of what is known today and the possibilities yet to be developed, he was of the opinion that the turboprop-type engine will be used on air transports of the future. He showed a few proposed designs of such aircraft.

Polytechnic Institute of Brooklyn

Arthur Barazotti, *Secretary*

Chairman Fritz Blomback opened the February 17 meeting, attended by 42 members, by the showing of *The Viking*, a film released by the Naval Research Laboratory in Washington, D.C. This film gives the story of the Martin Viking rocket, which has a Reaction Motors power plant, from the time of its assembly at the factory through its firing sequence at White Sands, N.M.

On February 24, Chairman Blomback met with 47 members to make the final plans for the field trip on the following day to Republic Aviation Corporation.

Purdue University

LaVerne G. Eklund, *Chairman*

On February 17, 90 persons were present to hear Morgan M. Blair, Chief Aerodynamicist, Columbus Division, North American Aviation, Inc., present a lecture on "The Physical Concept of Some Aerodynamic Parameters."

Immediately before Mr. Blair was introduced, two films entitled *The AJ-1 Attack Bomber* and *This Is Airpower* were shown.

Chairman LaVerne G. Eklund presided.

▶ At a joint A.S.M.E.-I.A.S. Student Branch meeting held on February 24, G. E. Chapman, Supervisor of Turbojet Performance and Aerodynamics Design Group for General Motors Corporation's Aeroproducts-Allison Division, gave an illustrated talk on "Some Engineering Aspects of Turbojet Engine Design."

Tom Tyler, Chairman of the A.S.M.E. Student Branch at Purdue, led the meeting; 60 persons were present.

Syracuse University

Charles E. Rogers, *Secretary*

The last meeting of the fall semester was opened by Chairman Bob Mack on January 14 with ten members present. The minutes of the previous meeting were read and approved.

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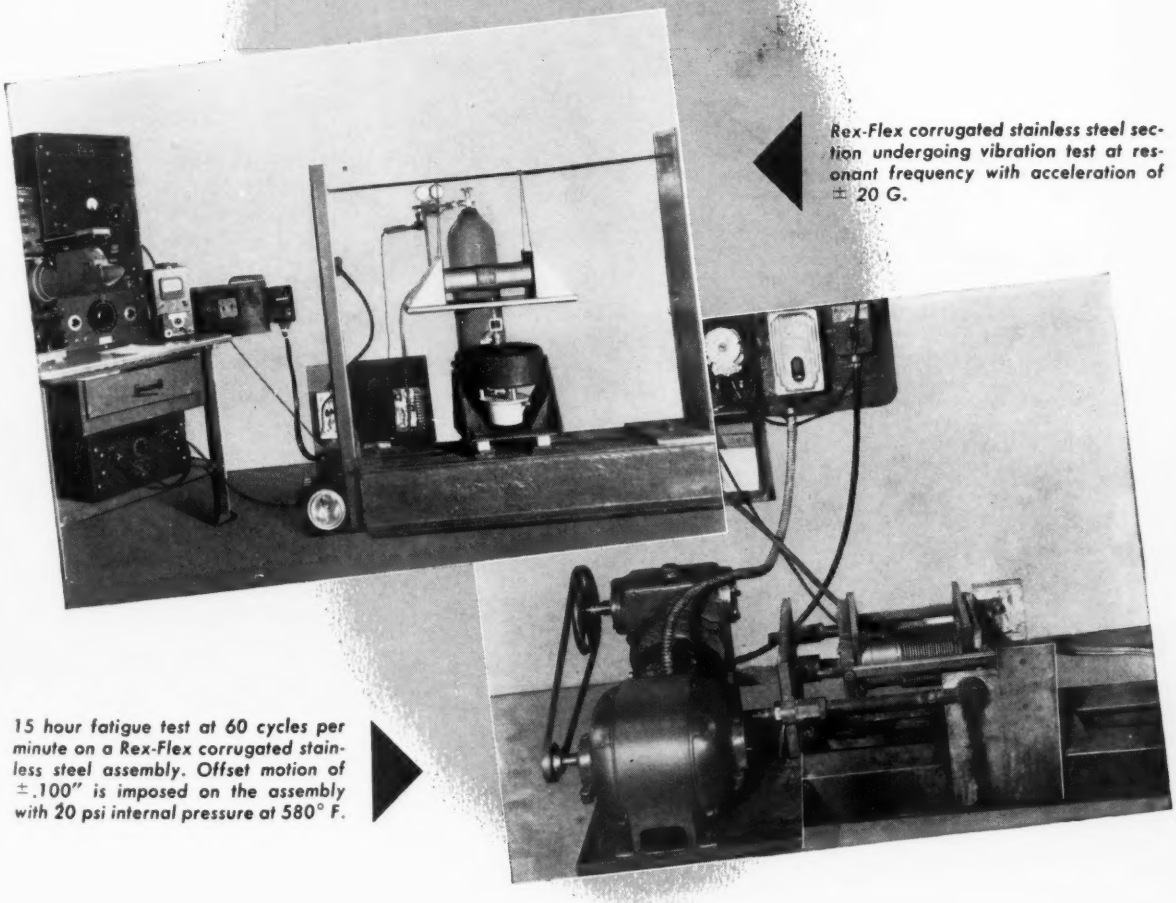

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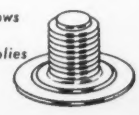

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It was agreed that the acknowledgments of the Ostrander Memorial Plaque contributions should be made immediately. This work is to be headed by David Birdseye and Charles Rogers.

Elections for the spring semester took place with the following results: Chairman, Fred Boenig; Vice-Chairman, David Birdseye; Secretary, Charles Rogers; and Treasurer, Fritz Hemmer. Ernest Hobbs voluntered his services to the Recruiting Committee.

Prospective members are to be invited to the second meeting of the new semester.

Refreshments were served after the business meeting.

University of Colorado

Franz Nawrocki, *Secretary*

Chairman Cloman D. Bogart called the February 4 meeting to order with 28 members present. He then read the announcement and rules of the First Annual Student Paper Competition conducted by the Texas Section on May 6–9.

At the conclusion of the business part of the meeting, a silent film on target drones was presented. This was followed by a talk by Prof. Karl D. Wood, Head of Colorado's Aeronautical Department, who gave a review of the recent I.A.S. Annual Meeting in New York.

University of Michigan

Hsueh-Ping Wu, *Secretary*

The first meeting of the spring semester of the 1952–1953 academic year was held on February 18 at the Michigan Union with about 35 persons present.

The following persons were elected to office for this semester: Chairman, Kirke Comestock; Vice-Chairman, Arthur Sotak; Secretary, Hsueh-Ping Wu; and Treasurer, Gordon Fox. The faculty adviser is Professor Wilbur Nelson.

Plans for the University of Michigan's one-hundredth year engineering-anniversary open house were discussed. The Student Branch will set up some display to represent the Aeronautical Engineering Department.

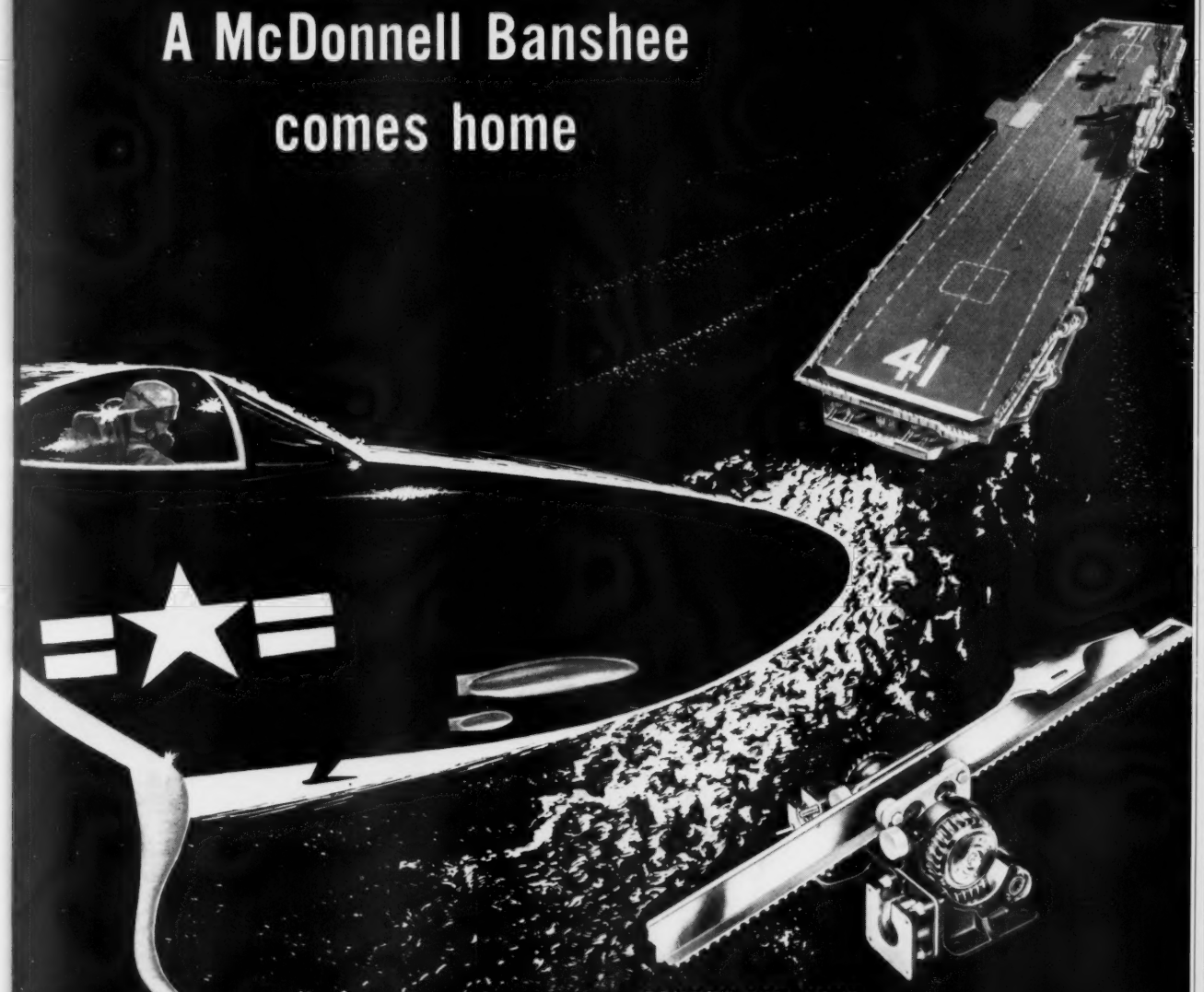
The motion picture, *Flight Log*, was shown to the audience. This film depicts the historical development of present-day aviation fuel.

University of Toronto

S. R. Swanson, *Secretary*

On January 14, 14 students were present to hear Kenneth Gauthier, Personnel Director of Bell Aircraft Corporation, speak on "The Importance of Personnel Relations." Chairman Ron M. McKee presided at the meeting.

A McDonnell Banshee comes home



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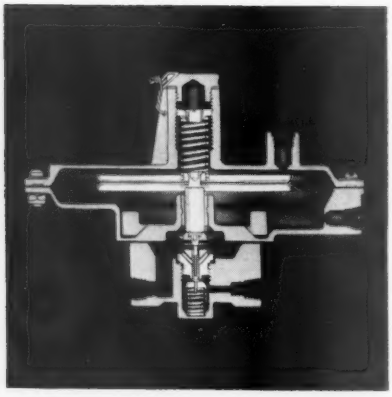
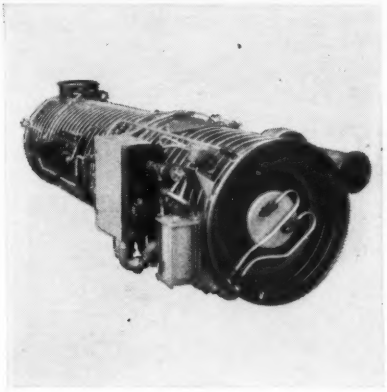
4

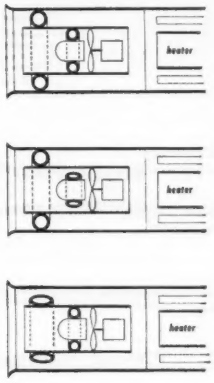
FUEL/AIR RATIO CONTROL



World War II stabilized the need for a dependable and efficient aircraft heater. In their efforts to supply this need, Janitrol engineers immediately encountered a number of variable conditions all directly affecting heater performance. Such things as plane speed, air pressure and temperature, size of aircraft, ductwork arrangement, exhaust restrictions, flight attitude, intake air scoop location, boundary layer conditions, had to be considered. Janitrol engineers decided that clean combustion should be the heart of the heater and they set to work on methods to maintain a relatively constant fuel-air ratio over a wide range of design requirements and service conditions.

This thinking led to the development of the air-loaded fuel pressure regulator, which varied fuel supply in relation to combustion air pressure. This approach solved the immediate problem, and in addition greatly simplified aircraft heater design and application. Today, this principle gives the aircraft designer maximum freedom in location of scoops and ducts while assuring proper combustion, efficient use of fuel, and ease of maintenance.





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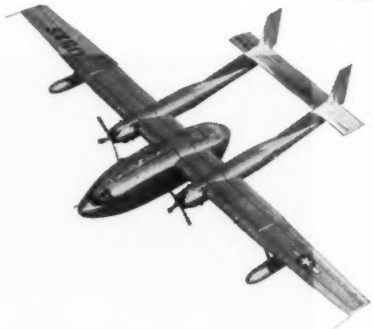

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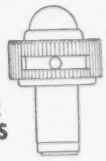
OR THIS 

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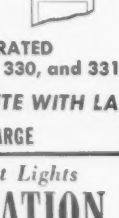

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The University of Tulsa

Robert Wolfe
Secretary-Treasurer

The University of Tulsa Student Branch enjoyed a field trip through the Tulsa Division of Douglas Aircraft Company, Inc. At this plant, B-47 jet bombers are being produced and modified.

Joe Johnson, Head of Engineering Personnel, and Owen Anderson, a 1951 Tulsa graduate, escorted the members through the plant. The trip began at the loading-in dock and continued through to the flight line. Nearly every phase of work was examined during the 3-hour period.

A special point of pride at the Tulsa Division is a 70,000-ton Hydropress costing $261,000. The plant employs over 200 engineers and expects to reach full production capacity in approximately 2 years.

Many schools have already taken advantage of this opportunity to get a close-up of the B-47; it is recommended for other colleges in this area.

▶ The February 19 meeting was called to order by Chairman E. H. Roberts. Minutes of the past meeting were read and approved.

After the completion of the business portion of the meeting, two Douglas Aircraft films were shown. These were *Look to the Skies* and *The Story of the Helicopter*. The meeting was adjourned at 9:15 p.m.

University of Wichita

Wilbur Middleton, *Secretary*

Two films were shown at the February 13 meeting at which Chairman Don Hufford presided and nine persons were present. The pictures shown were Consolidated Vultee Aircraft Corporation's *The Skate* and the U.S.A.F.'s *The B-47 Story*.

Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Eber, Gerhard R., Ph.D. (Dr. Ing.), Chief, Aerophysics Div., Aeroballistic Research Dept., Naval Ord. Lab. (White Oak).

King, John W., M.Sc., Capt., U.S.N.; Chief of Staff, Naval Air Material Center (Philadelphia).

Puvrez, Paul A., Ing. Aero., Technical Officer, Airworthiness, ICAO (Montreal).

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DC PREAMPLIFIER

AC PREAMPLIFIER

DC CONVERTER—for low level DC recording such as thermocouple output.

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THRESHOLD MONITOR provides means for the control of voltage levels or rate of change.

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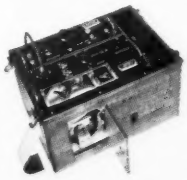
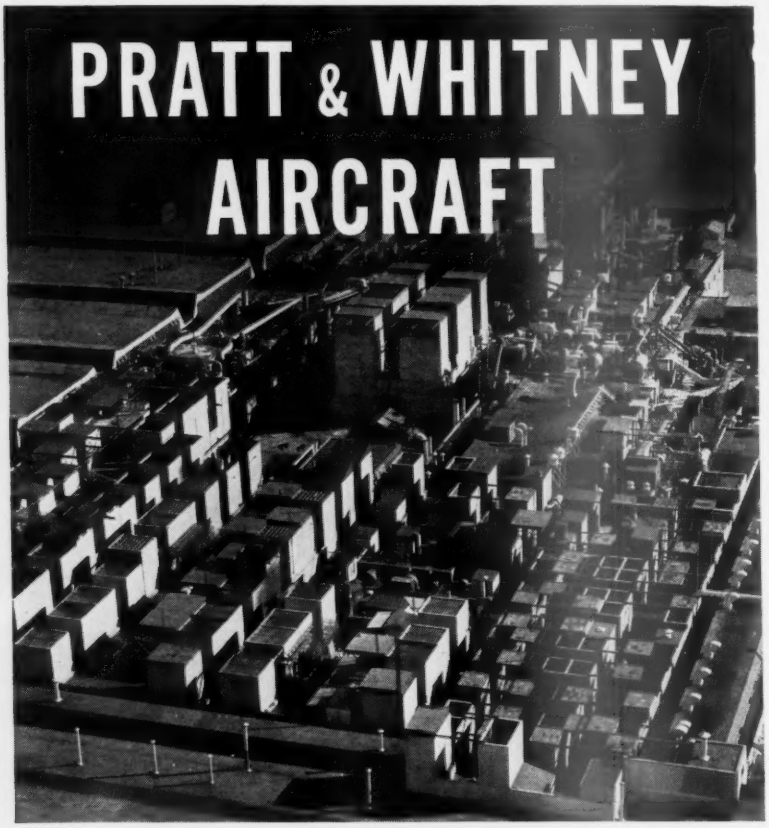


SANBORN 1-, AND 2-CHANNEL RECORDING SYSTEMS

One channel Model 128/141 above and two-channel Model 60 at right both incorporate Sanborn recording advantages which include interchangeability of amplifiers and (with Model 60) preamplifiers.



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Transferred to Associate Fellow Grade

Kee, Robert M., B.S. in Engrg., Proj Engr., Rotor Blades, Sikorsky Aircraft Div., United Aircraft Corp.

Elected to MEMBER Grade

Andes, John P., B. of Ae.E., Research Aerodynamicist, Cornell Aero. Lab., Inc.

Balzer, Joseph F., Design Engr., Douglas Aircraft Co., Inc. (Long Beach).

Bond, William T., B.S., Design Engr.—Structures, Hayes Aircraft Corp.

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Pelland, L. A. J., Technical Officer in charge of Model Aircraft Design, National Aeronautical Establishment (Montreal).

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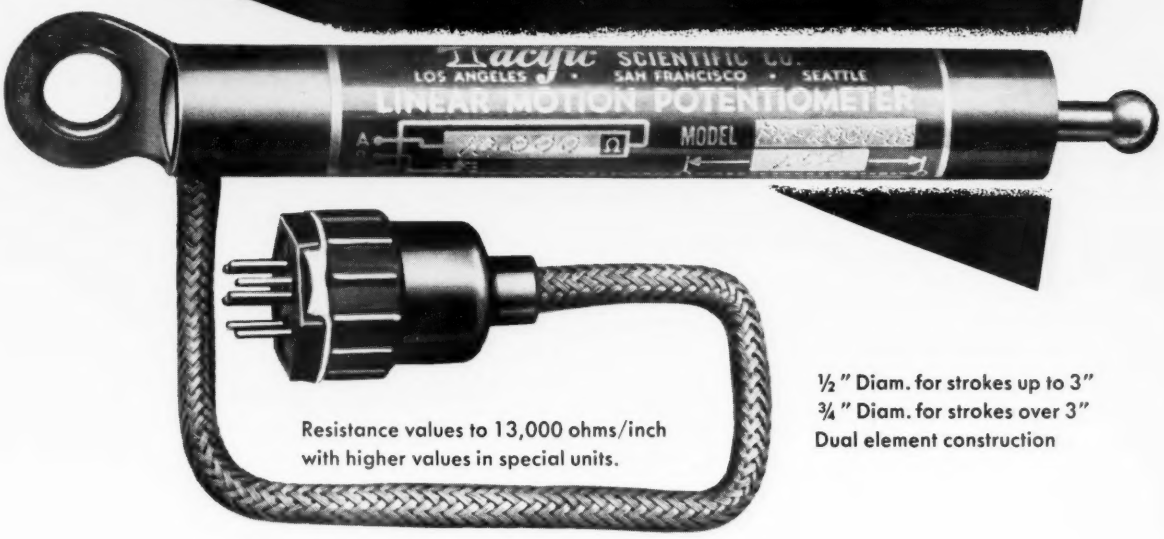

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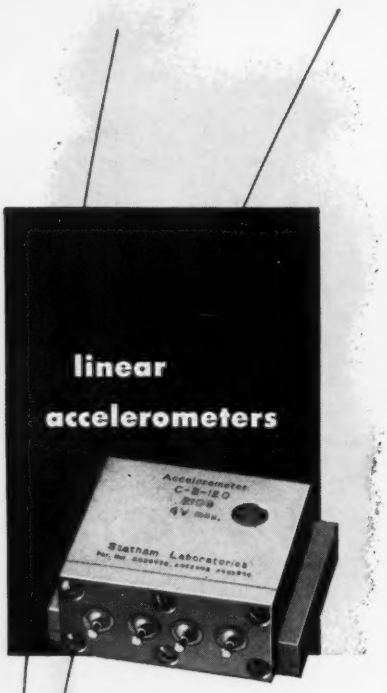

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Stoddard, Clifford P., B.S., Design Engr. & Supvr., Marquardt Aircraft Co.

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Summers, Robert Allan, S.M. in Ae.E., Research Asst., Instrumentation Lab., Massachusetts Institute of Technology; Engrg. Cons. to Convertawings, Inc.

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Jobe, M. B., B.S., Asst. Sales Mgr., Goodyear Aircraft Corp.

McCormick, Harry E., B.S., Writer, Technical Publications, Globe Corp., Aircraft Div.

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NEW SUPER HAULS FREIGHT FASTER, CHEAPER

On the opposite page you see illustrated the rear loading area of a big Super Constellation 1049-D, designed to carry more freight farther, faster and cheaper than ever before in history—closely approaching the sought-after 5¢ per ton-mile operating cost.

This all-cargo version of the Super Constellation culminates 7 years of special cargo research by Lockheed and is so different from the passenger versions that the fuselage requires separate production jigs.

The 1049-D utilizes the most economical form of power available to aircraft, the turbo-compound engine. Four of these Wright engines, each rated 3250 horsepower for take-off, give the Super Constellation a 332-mph cruising speed at 20,000 feet. It will fly the 3,459 miles from New York to London non-stop in 13½ hours with a payload of 14 tons, crew of 5 and full over-water equipment—will fly 24,500 lbs. non-stop to Berlin.

DESIGNED TO CUT COSTS

The Super Constellation was designed for "loadability," so as to assure maximum efficiency and cut costs in man-hours.

Total usable payload volume is 5568 cu. ft., equivalent to a storeroom 46.4 ft. by 15 ft. and 8 ft. high. Total floor area for cargo is 1032 sq. ft.

The integrated all-magnesium floor is the finest being installed in any air transport today, according to both commercial and military operators who have inspected it. Concentrated loads from skids and legs may exert up to 400 lbs. per square inch. Floor loads of 1000 lbs. per lineal foot or 300 lbs. per square foot may be applied in the main cabin.

SPECIAL TIE-DOWNS AND BUILT-IN CONVEYOR

Floor tie-down fittings in a grid pattern of approximately 20" x 20" provide for loads of 4,000 lbs. in any direction. Wall tie-downs will take up to 4,500 lbs. each.

At a push of a button the built-in conveyor will pull (or *push*) loads over 12,000 lbs. on rollers or dollies or will skid a load of 8,000 lbs., reducing man power to a minimum.

The all-cargo Super Constellation is completely heated, pressurized and refrigerated. Normal equipment includes dual heaters, superchargers and refrigeration units. This gives cargo operators complete freedom in operational planning and insures protection of the cargo, regardless of its type or the nature of the operation.

Leadership demands constant achievement

Air freight gets a new lift...via

SUPER CONSTELLATION

FARTHER—FASTER—CHEAPER! This has been the objective of all transportation since man invented the wheel. And civilization itself has progressed in direct ratio to improvements made in transportation.

Now, the new all-cargo Super Constellation will carry more things *farther-faster-cheaper than any commercial plane.* It will carry 35,000 pounds of cargo coast-to-coast in less than 8½ hours at the lowest cost in history. It will carry 27,500 pounds New York to London *non-stop* in less than 14 hours! That's a new lift for air freight.

All-cargo Super Constellations will soon serve Seaboard & Western and other leading operators.

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Elected to Technical Member Grade

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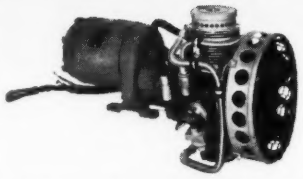
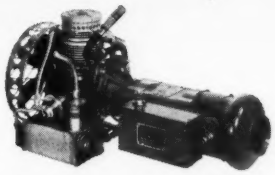
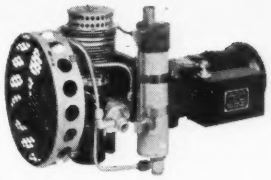
Woodward, Frank A., A.E., Ballistician, C.A.R.D.E. (Quebec).



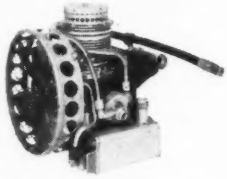
Airborne. 400 cycle — 208v AC drive. Horizontal sump.



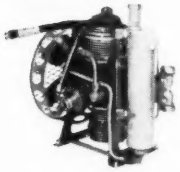
Airborne. 28v — 3½ hp motor. Horizontal sump. Radio noise suppressor.



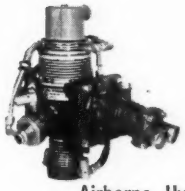
Airborne. 28v — 3½ hp motor. Vertical sump. Radio noise suppressor.



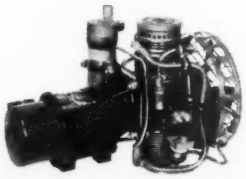
Airborne. Hydraulic drive. 1500 lb. hydraulic system. Horizontal sump.



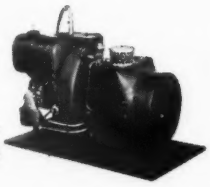
Airborne. Hydraulic drive. 1500 lb. hydraulic system. Vertical sump. Pressurized inlet.



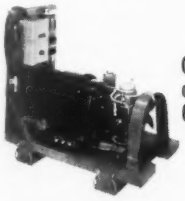
Airborne. Hydraulic drive. 3,000 lb. hydraulic system. Pressurized inlet. Remote sump.



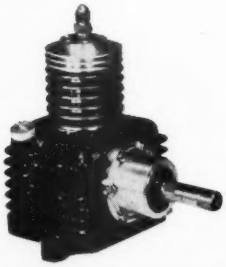
Airborne. 28v—2 hp motor. Vertical sump. At sea level, and at 15,000 ft. delivers 2 cfm of free air compressed to 3,000 psi.



Ground application. Here a portable gasoline motor is used as a driving unit.



Ground application. Here the compressor can be driven by a 60 cycle 220 volt motor.



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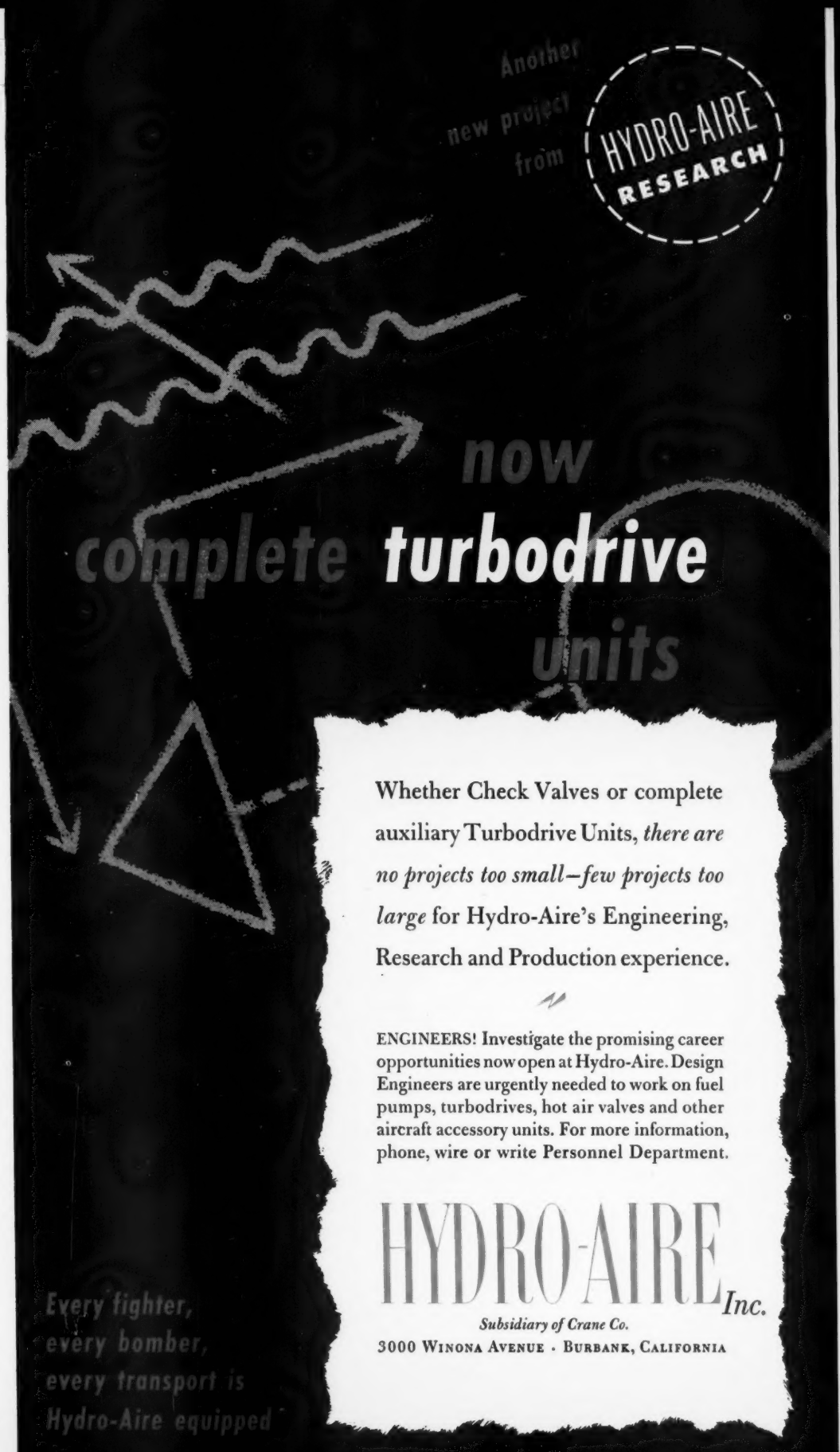
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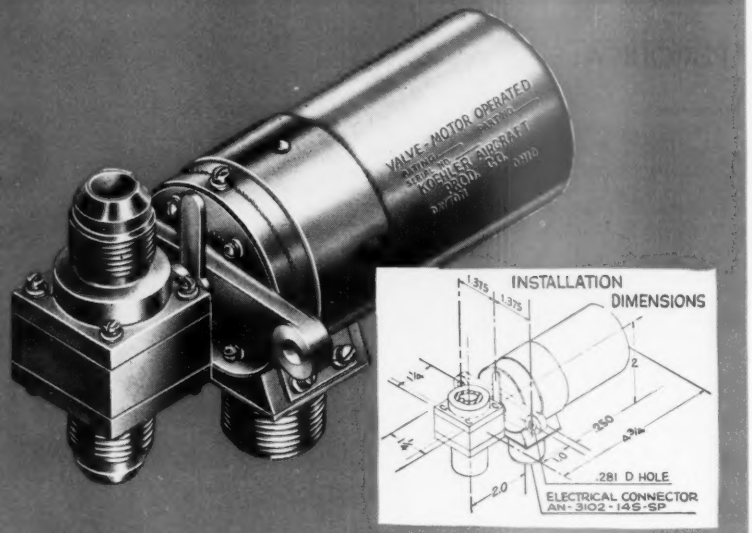

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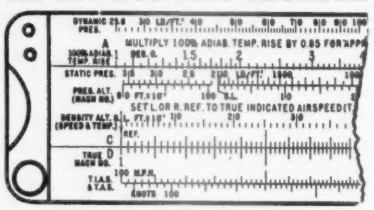

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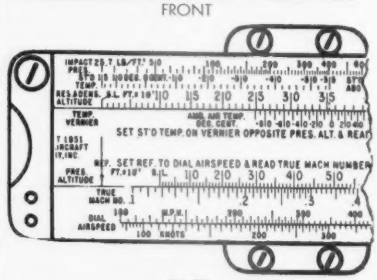

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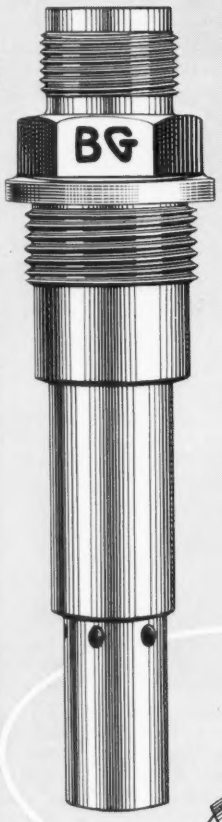

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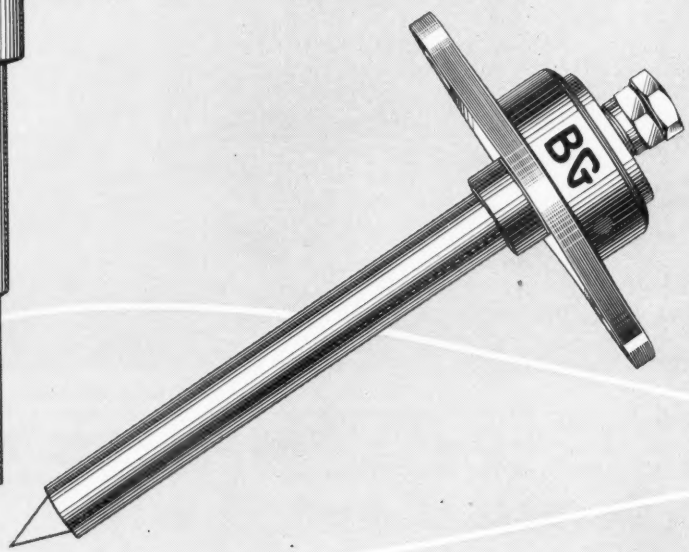

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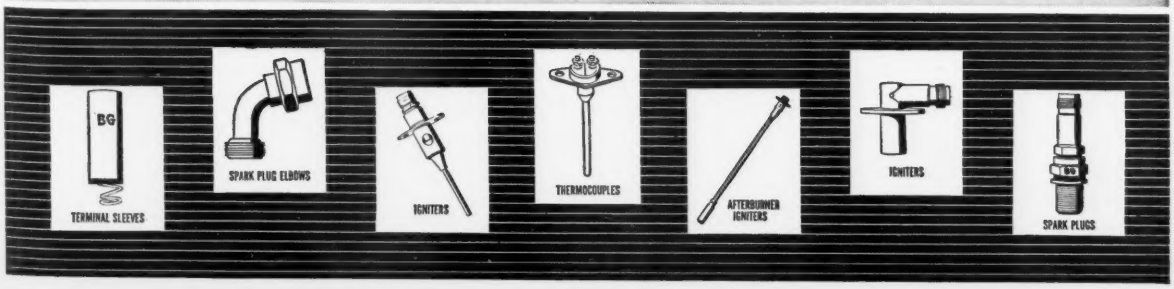

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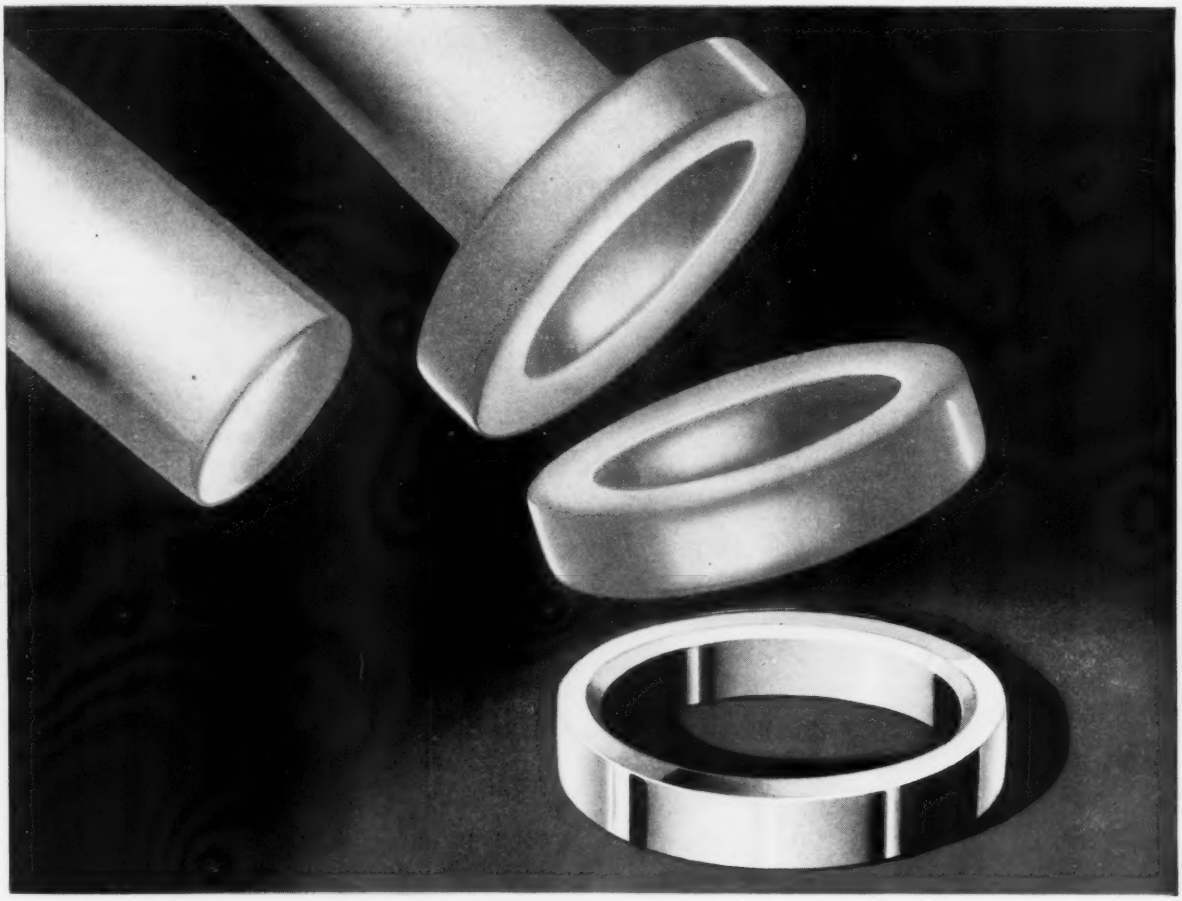

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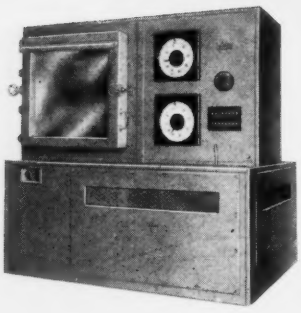

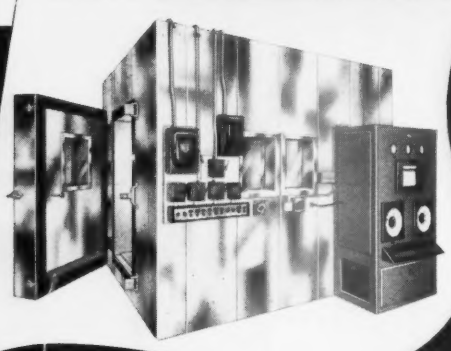

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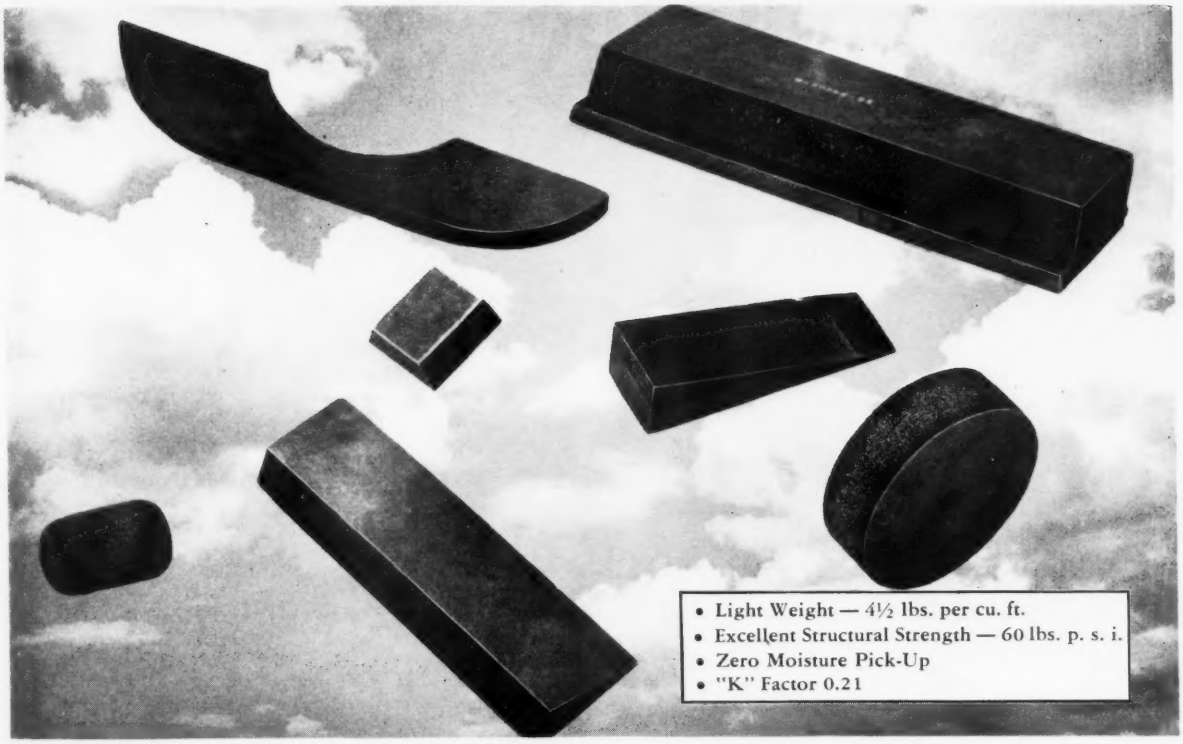

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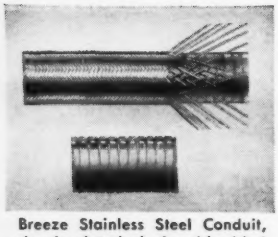

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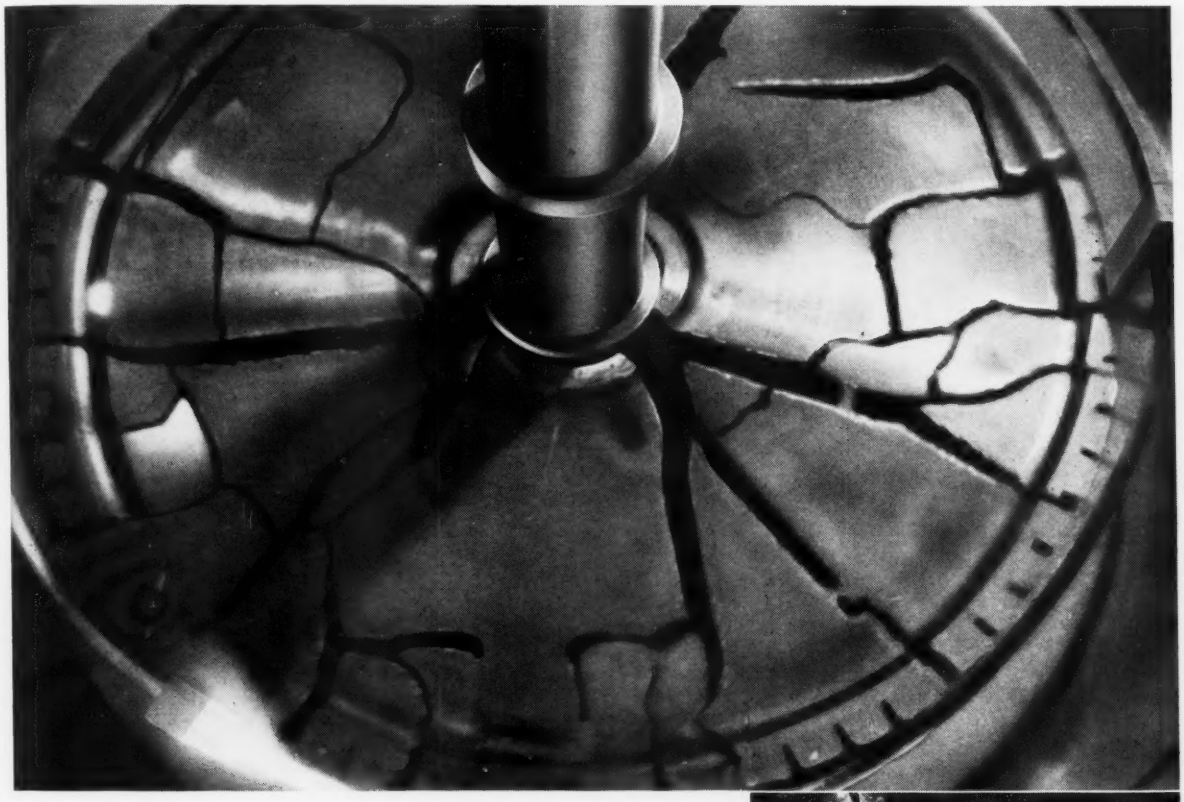

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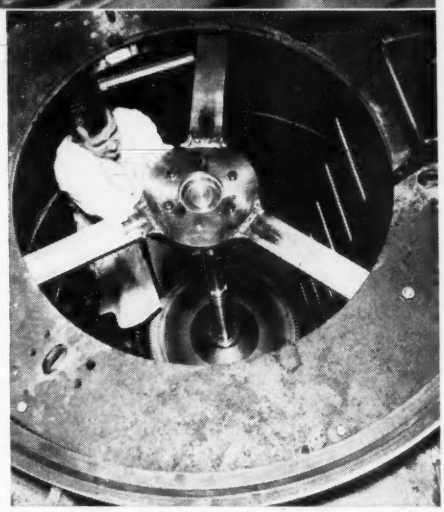

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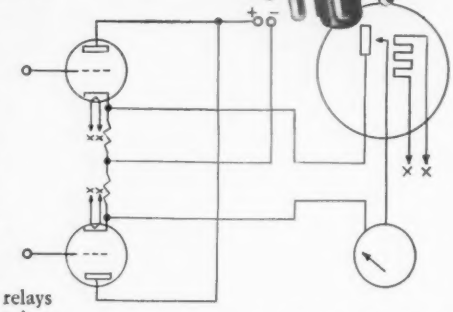

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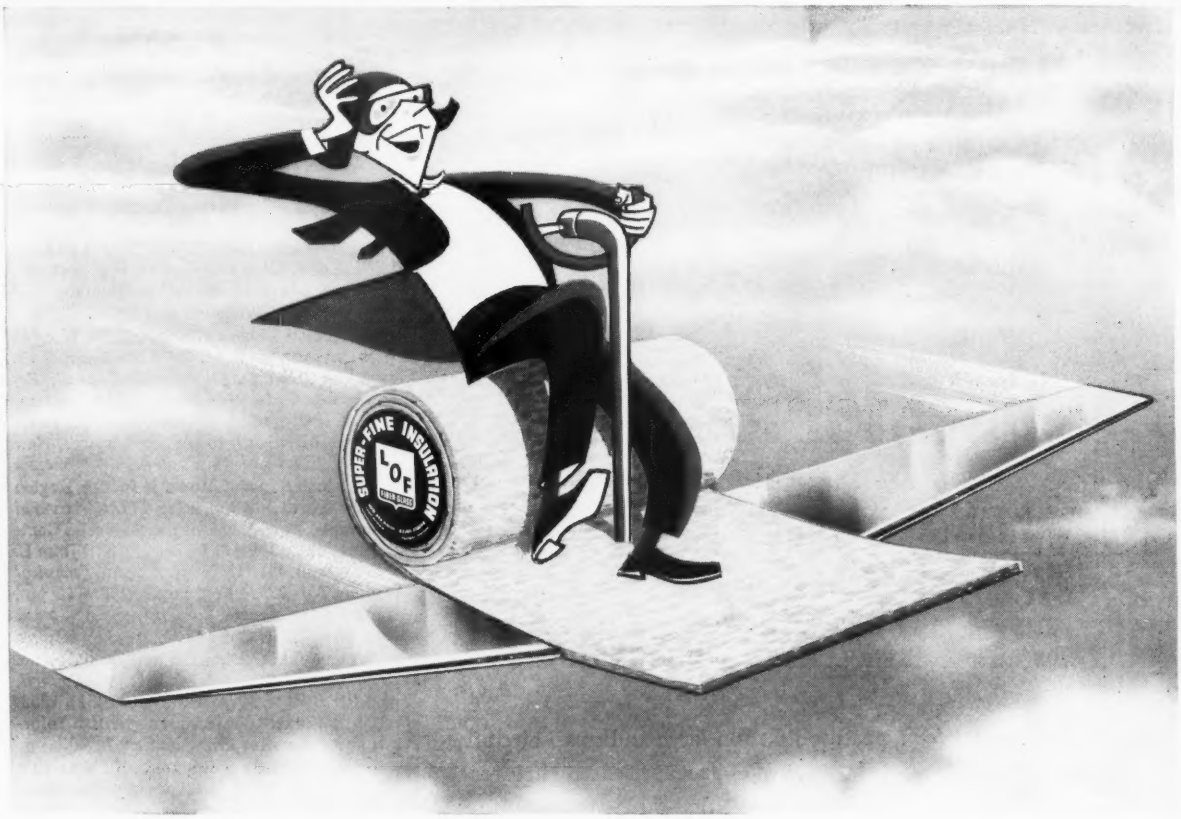

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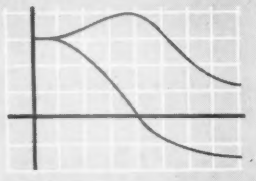

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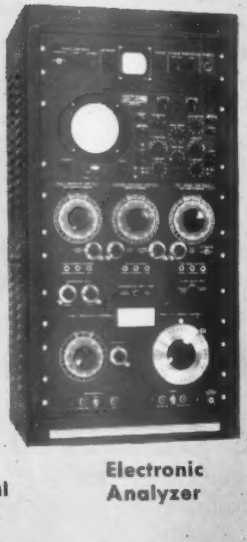

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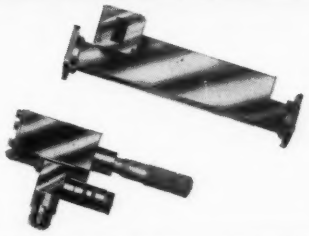

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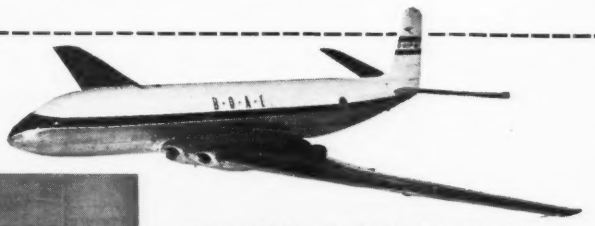

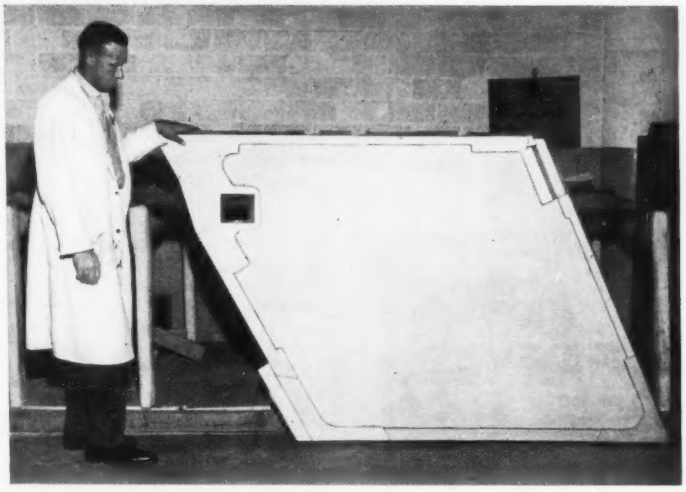

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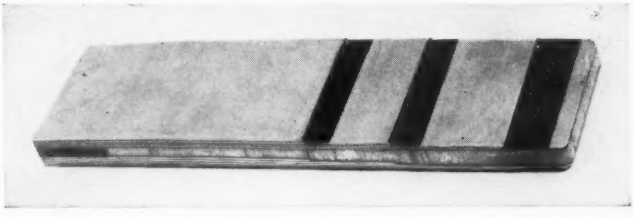

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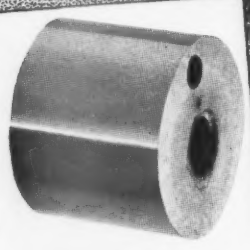

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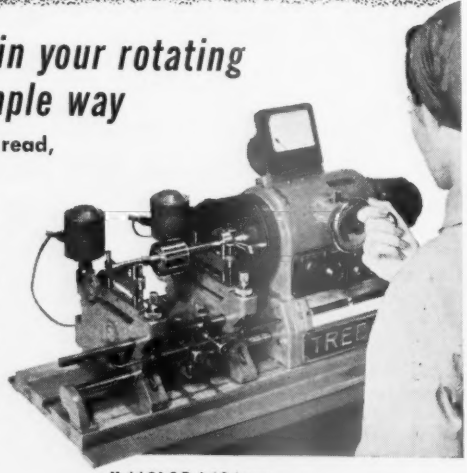

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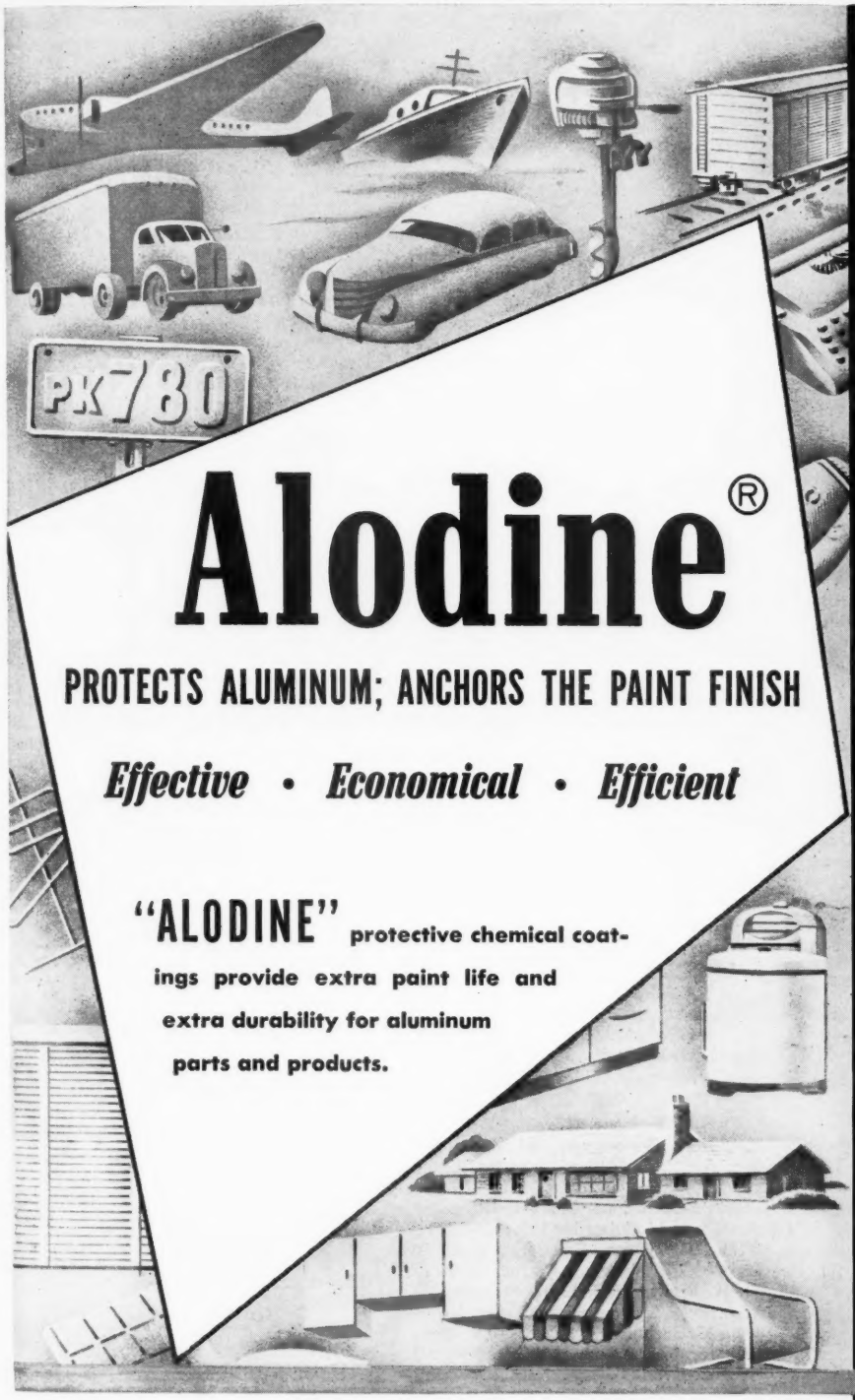

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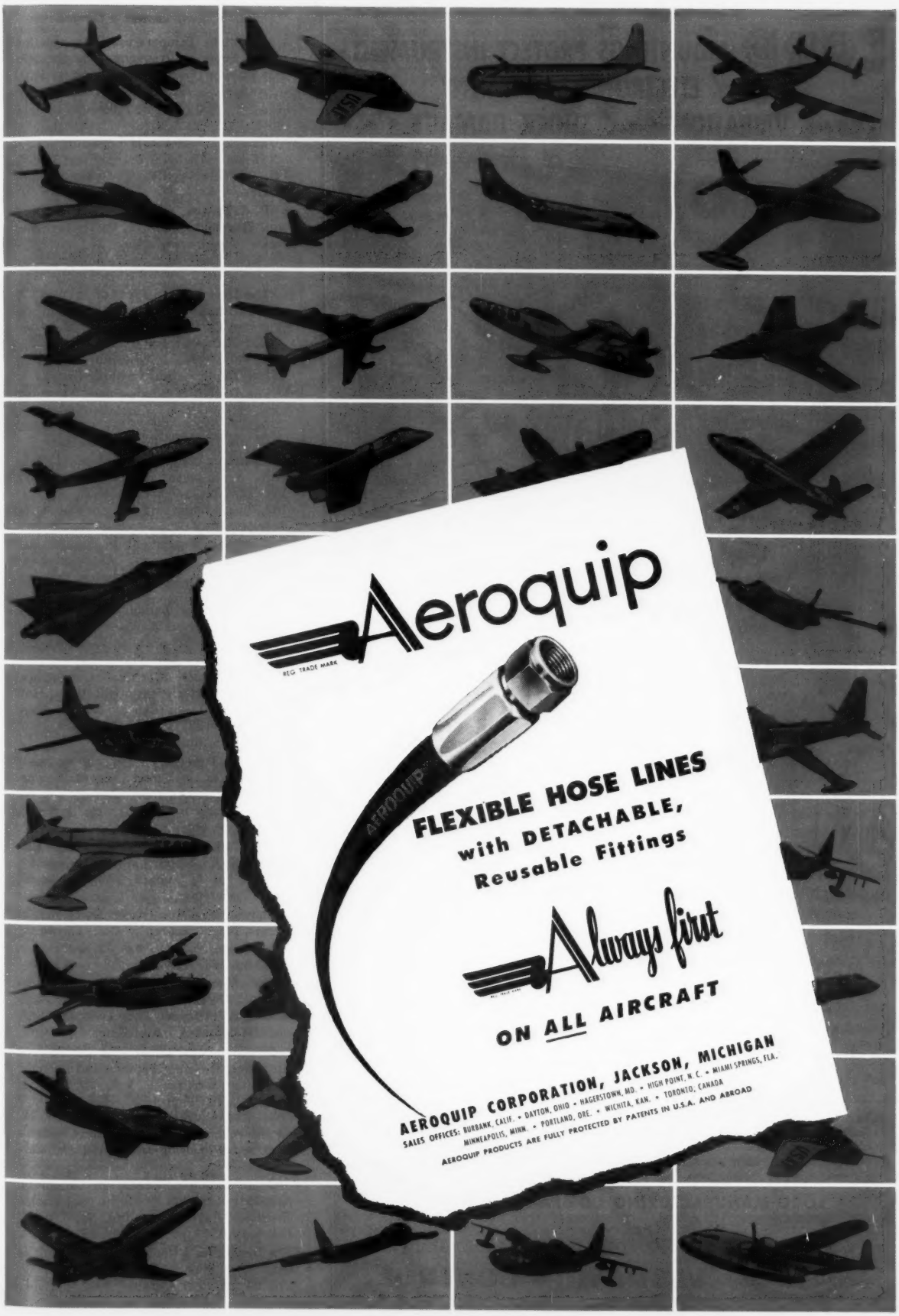
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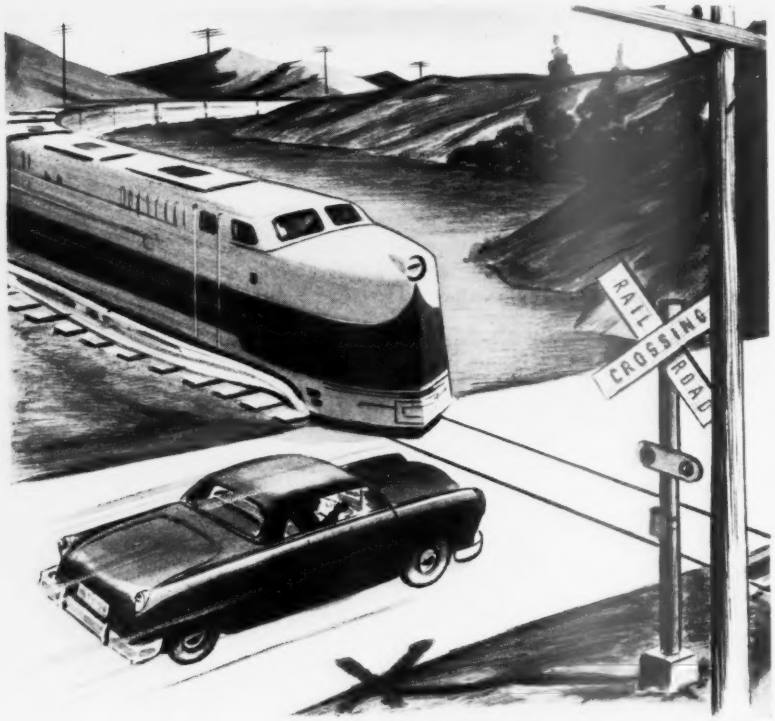

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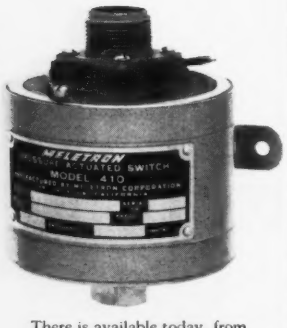

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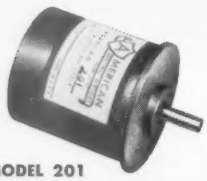

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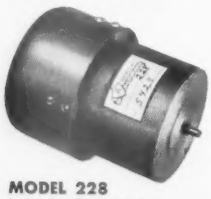
Synchronous Drive Motor



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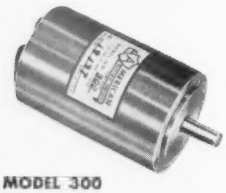

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Reluctance Type
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MODEL 168
Propeller Fan

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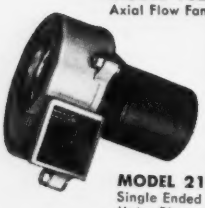

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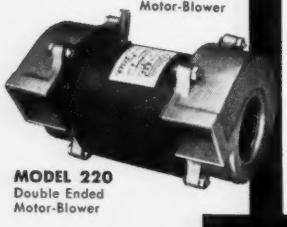

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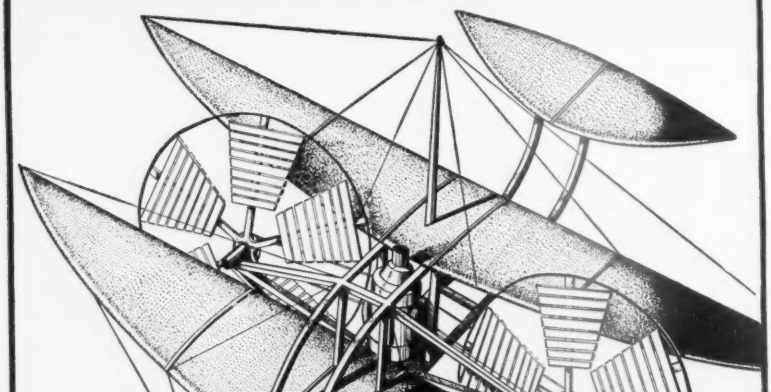

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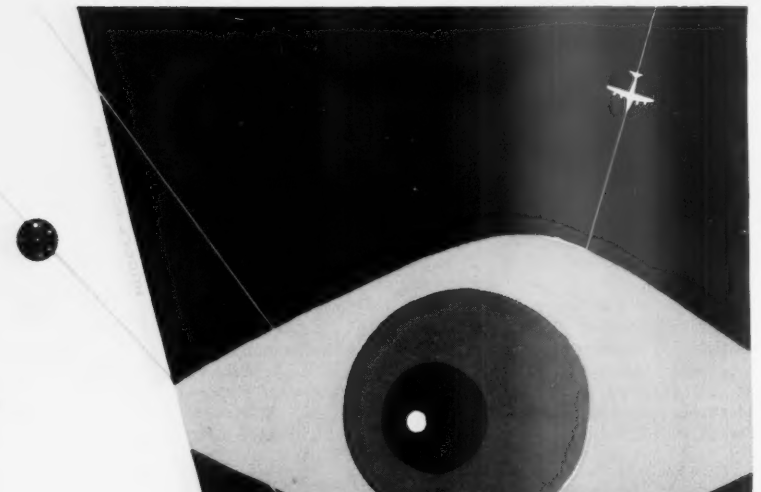

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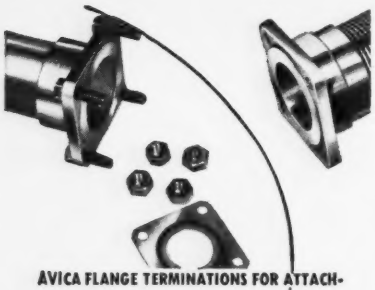

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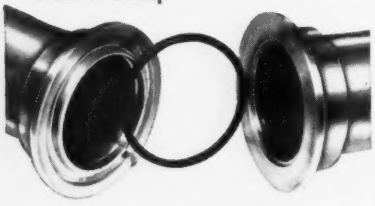

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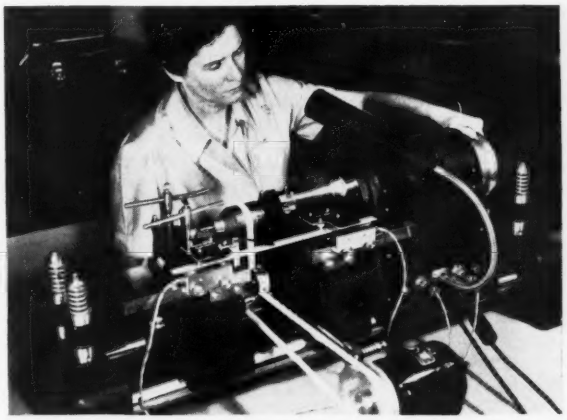

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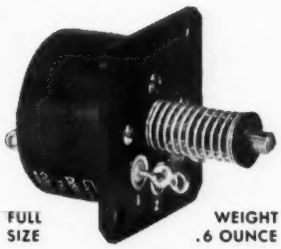

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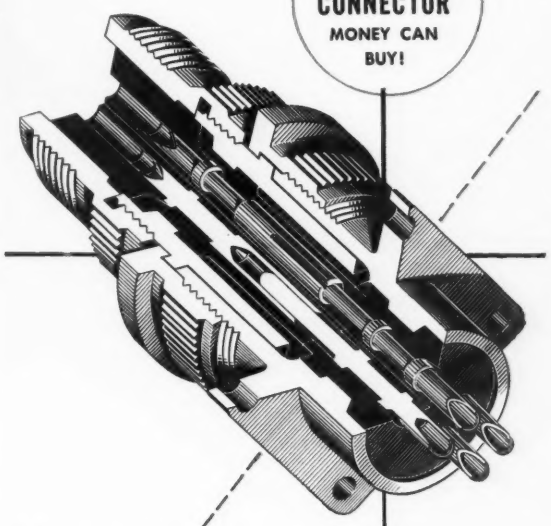

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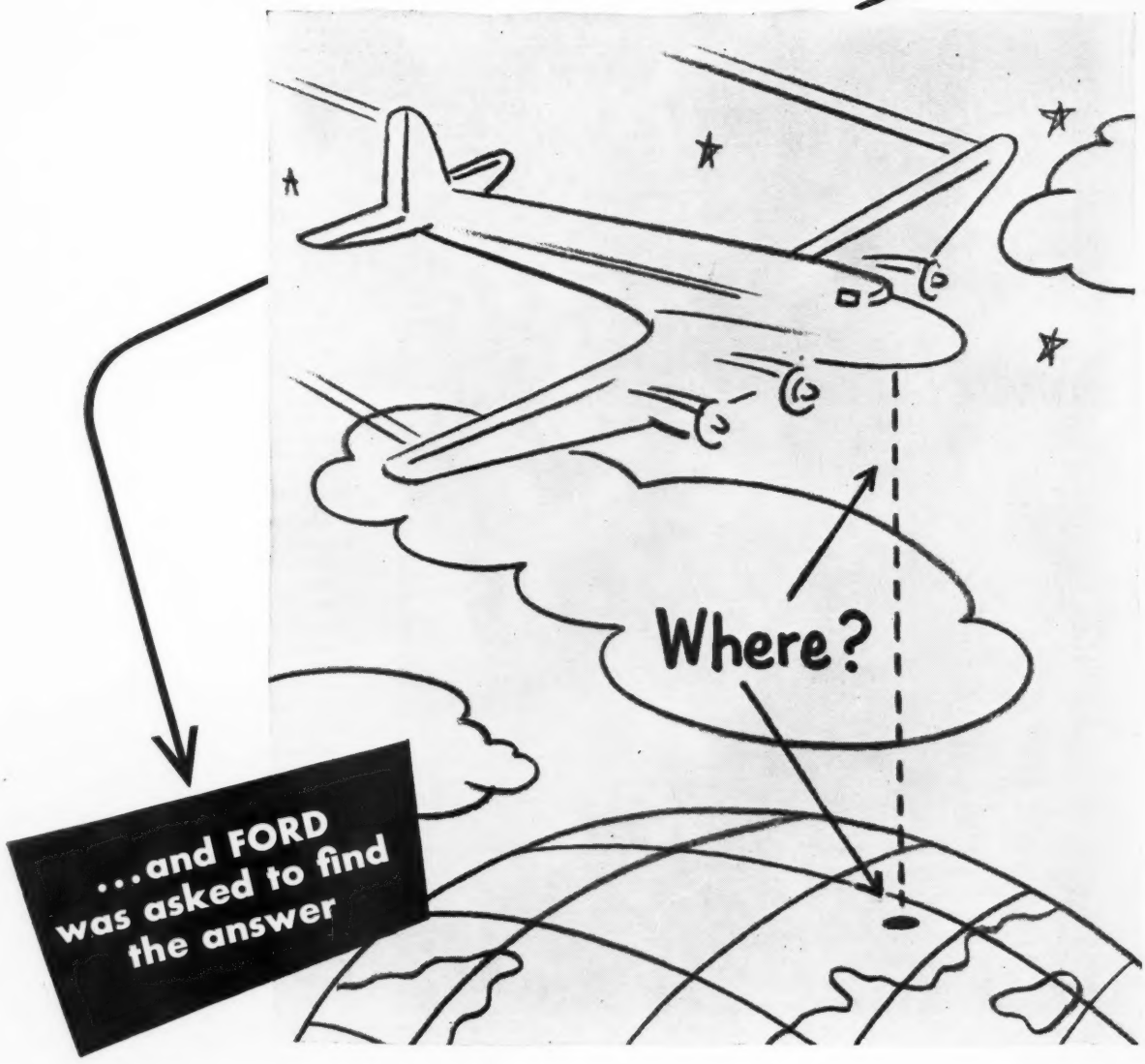

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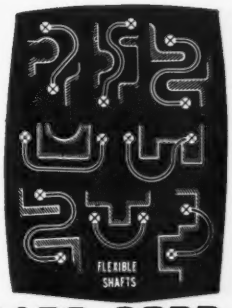

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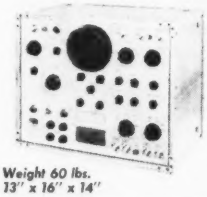

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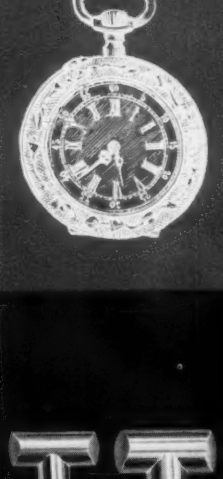

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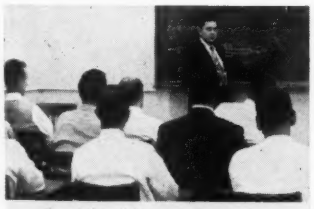

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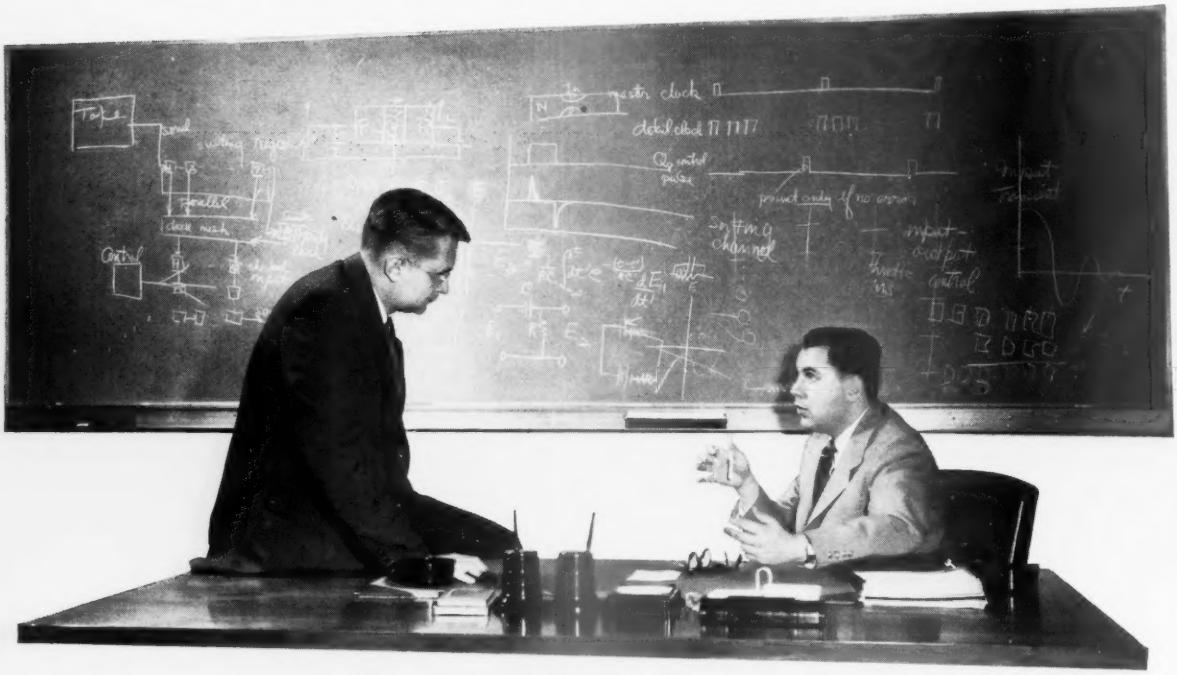

Dr. E. C. Nelson (left), Head of Computer Systems Department, and J. H. Irving, Head of Systems Planning and Analysis Department, discuss a problem in the systems planning and analysis stage.

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Aeronautical Reviews — BOOKS

Weight-Strength Analysis of Aircraft Structures

By F. Shanley. New York, McGraw-Hill Book Company, Inc., 1952. 394 pp., diagrs., figs. $8.50.

The aircraft industry has always been concerned with adequate strength of its structures and with the minimum possible weight as well. Because of the importance of providing adequate strength at a minimum weight, materials and structures are often evaluated on a strength/weight basis. The author points out, however, that comparison of materials on strength/weight basis may be highly misleading for structures that fail by buckling, for in such cases the proportions of the structure have a strong influence on the buckling strength. Further, the author has shown in a previously published paper that in general the strength/weight factor is not the reciprocal of the weight/strength factor.

Since, in an airplane structure, the primary object is to reduce weight, not necessarily increase strength, the weight/strength basis follows logically in evaluating structures.

The author has been particularly successful in presenting his analytical methods for investigating various optimum design principles.

This volume of 394 pages is divided into three parts titled "Principles of Optimum Structural Design," "Structural-Weight Equations," and "Material Properties and Behavior."

To indicate the scope of these sections, it might be worth while to list a few of the subjects covered. In the first section, for example, there are considered the minimum weight of simple and wide columns, of panels, and of cylindrical and stiffened shells in bending. In addition, such matters as optimum overall design, straight-line area approximation, and volume of material required for members carrying transverse loads are a few other approaches used in analyzing structures. The effect of torsional stiffness requirements on wing structural weight is also covered.

Part II covers various structural weight equations and analyses relating to sheet-stringer-rib type of structure, effective depth of airfoil sections, inertia and shear reduction factors, wing ribs and secondary structure, nonoptimum structural weight, thick-plate type of wing structure, thin-wing structures, and fuselage and shell structures.

Part III concerns itself with analyses of stress-strain-time relations, creep, and inelastic-column theory.

The author expresses the hope that the publication of the book will serve as an incentive to further development of the principles of weight/strength analysis, not only for aircraft, but for all types of structures. The author is to be congratulated on such an excellent beginning.

FREDERICK K. TEICHMANN
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Daniel Guggenheim School of Aeronautics
New York University

Electric Fuses

A Critical Review of Published Information. By H. Läpple. London and Toronto, Butterworth & Co., Ltd., 1952. 173 pp. $5.00.

The fuse designer and the engineer concerned with the protection of electric circuits and apparatus will find this little volume a valuable contribution to his reference library. Beginning with the invention of the simple "weak-link" by Thomas A. Edison in 1880, the fuse has had an extremely interesting developmental history leading to the present reliable precision device. The author has traced this development by means of a critical review of the published literature. As the Chief Engineer of the High Voltage Fuse and Over Voltage Protection Department of Siemens-Schuckertwerke, Berlin, he is well qualified to prepare this information, which he did for the British Electrical and Allied Industries Research Association.

After a brief introduction and a short history of fuse development, the author reviews the circuit breaking process, which is essentially concerned with the arcing period of the fuse operation. The methods of circuit interruption as employed in cartridge fuses, expulsion fuses, liquid fuses, and current-limiting fuses are discussed.

Closely related is the subject of the "breaking capacity" of fuses, dealt with in the third chapter. Prior to about 1920 knowledge of the breaking capacity of fuses was limited, due partly to lack of high-power testing facilities and partly to the low values of short-circuit current in most systems at that time. Since then, many engineers have studied the theoretical and practical aspects of arc extinction and have greatly increased the breaking capacity of fuses. Most noteworthy is the introduction of the current-limiting fuse which is designed to clear a short circuit before the current can build up to the maximum available short-circuit current.

The fourth chapter is a short account of the problem of the deterioration of the fuse element due to corona effects. The deterioration is due partly to the bombardment by ionized particles but principally to the chemical effect of nitrous oxides produced by the corona. However the modern high-voltage fuse appears to be free from corona deterioration because of the construction of such fuses.

The subject of time-current characteristics of fuses is reviewed in considerable detail in chapter five. First, the portion of the characteristic for which the time is of the order of $^1/_{10}$ second or less, in which the heat loss from the fusible element is negligible, is discussed. In this portion, which lends itself most readily to mathematical treatment, the quantity "I^2t" is a constant. For longer times, heat emission must be considered and the analysis is far more complex. Many simplifying assumptions have to be made to apply mathematical analysis. The "Newton characteristic," for example, is determined by assuming that the heat dissipation follows Newton's law of cooling. The author points out the value of plotting time-current characteristics on log-log paper and shows how the dimensionless form of the equations assists in analy-

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sis. A number of empirical formulas are also discussed, which closely match actual characteristics.

This chapter also includes a review of the definitions of the various quantities associated with fuse characteristics, of the standard methods of measurement, and of time-lag fuses. The problem of selectivity among fuses (discrimination) and of coordination with other apparatus is reviewed. Finally, the effects of surge currents on fuse elements are discussed.

The sixth chapter compares the ratings, rules, requirements, and standards of fuses of the standard associations in the United States, Great Britain, and Germany. A list of such standards of the three nations is given at the end of the chapter.

The final chapter reviews the special fields of application for fuses. A valuable application is the use of fuses combined with other protective devices whereby the fuse permits the use of lighter equipment by protecting against short circuit conditions. The current-limiting fuse is most suitable for this type of application.

The latter half of the book contains an extensive bibliography of fuses with an abstract of each reference. The fuse designer, in particular, will find this list of references most valuable.

Although the material presented in this book is of general application, the aircraft electrical engineer and the designer of fuses for aircraft will find no discussion of fuses for aircraft. It would be well for the author to include such material in a future edition. The special problems of coordination and selectivity should be discussed as well as the effects of the extreme temperatures encountered. The effect of the 400-cycle a.c. operation on breaking capacity as compared to 60-cycle operation should be included. A comparison of aircraft fusing practices in various countries with references to the standard specifications of these countries would be most instructive.

I. MATTHYSSE
Chief Design Engineer
Burndy Engineering Company

Book Notes

ELECTRONICS

Proceedings of the National Electronics Conference, Volume 8. Chicago, September 29, 30, and October 1, 1952. Chicago, National Electronics Conference, 1953. 835 pp., illus. $5.00.

This volume contains, with only one exception, the complete edited text of all technical papers and luncheon speeches presented at the conference. Approximately 100 papers are presented under 22 headings. Sections of particular interest will be those on servomechanism theory; magnetic amplifiers and servo applications; equipment and components reliability; radio navigation; components, assembly, and measurements; computers; antennas; and coding and recording techniques. The volume is profusely illustrated with photographs and diagrams; references are given at the end of most papers. A useful appendix is the detailed table of contents of the previous six volumes.

ENGINEERING

How to Improve the Utilization of Engineering Manpower. (Executive Research Survey No. 2.) Washington, The National Society of Professional Engineers, 1952. 55 pp. $2.00.

This study pools the experience of more than 495 major industrial companies and engineering firms. The methods and procedures that they found helpful point the way for other companies with the same problem. In the introduction is surveyed the current need for engineers and engineering man power utilization in industry. The scope of the book is well illustrated by the chapter headings: Indoctrinating Engineers—Suggestions for Programs. Making the Existing Engineering Staff More Effective. The Use of Supporting Personnel. Are Engineers' Talents Being Wasted? Auxiliary Sources of Engineering Talent. Engineering Turnover—Causes and Results. Preparing the Engineers of the Future. How to Improve the Utilization of Engineering Manpower—Summary and Recommendations. A short reading list is appended.

EQUIPMENT

HYDRAULIC

Proceedings of the National Conference on Industrial Hydraulics, Vol. 6. 8th Meeting. September 4–5, 1952. Chicago, Graduate School of Illinois Institute of Technology and Armour Research Foundation of Illinois Institute of Technology, 1952. 242 pp., figs. $4.50.

The 21 papers presented at this meeting are reproduced in full, together with illustrations, diagrams, and edited discussions. Some of the papers that will be of particular value are: Design Features of a High Pressure Single Stage Rotary Vane Hydraulic Pump Motor, by J. R. England; Jet Engine Fuel Pumps, by J. A. Lauck; Design for Increased Reliability of Aircraft Hydraulic Systems, by L. M. Chattler; The Surface Type Seal—For Tougher Jobs, by R. O. Isenbarger; Tube and Tube Fittings, by Lee Schmohl; and Portable Tube-Working Tools, by George Franck.

Aircraft Hydraulics. Prepared by Naval Air Technical Training Command for Publication by the Bureau of Naval Personnel. (Naval Training Courses NAVPERS 10332-A.) Washington, U.S. Government Printing Office, 1951. 292 pp., illus. $0.75.

Contents: Introduction to Hydraulics. Hydraulic Principles. Fluid, Seals, and Tubing. Reservoirs and Filters. Hydraulic Pumps. Pressure Regulators. Selector Valves. Actuating Cylinders. Accumulators. Locks and Sequence Valves. Relief Valves. Auxiliary Units. Shock Struts. Brake Actuating Systems. Hydraulic Brakes. Shimmy Dampers. Hydraulic Systems. Hydraulic System Inspection and Maintenance. Hydraulic Turrets and Gun Chargers. Automatic Pilots.

INSTRUMENTS

Servomechanism Analysis. George J. Thaler and Robert G. Brown. New York, McGraw-Hill Book Company, Inc., 1953. 414 pp., figs. $7.50.

This text presents the essentials of the mathematical theory of servomechanisms. It is an outgrowth of courses that have been taught for four years at the University of Notre Dame at the postgraduate level. Most of it has also been used for three years at the University of North Dakota at the undergraduate level. Stressed throughout the work are the elements of analysis which are a necessary preliminary to design. After covering the basic tools for analysis and design, the authors detail the mathematical methods for analyzing servo systems. Included are lengthy discussions of transient analysis, polar transfer function, and logarithmic transfer function analysis. Physical explanations and worked examples follow the mathematical development. Two special features are the discussion of relay servomechanisms and the root-locus method, in which the concept of the pole and zero configurations for dynamic systems are utilized. The appendixes contain, in addition to reference tables, factual information about error detectors, controllers, servomotors, and compensating devices. Reference features of the book are a 206-reference bibliography and a good index of topics. George J. Thaler is Assistant Professor of Electrical Engineering at the U.S. Naval Postgraduate School, and Robert G. Brown is Senior Project Engineer, A.C. Spark Plug Division, General Motors Corporation.

Direct Current Machines for Control Systems. A. Tustin. New York, The Macmillan Company, 1952. 306 pp., figs. $10.

The aim of this book is to make the potentialities of rotary power amplifiers more widely known and more easily intelligible. It is intended to provide a basis for their further development, both in design and application. This treatise has been written not only for engineers and designers in electrical manufacturing concerns, but also to meet the needs of workers in research establishments and in Armed Services technical centers. Professor Tustin, of the University of Birmingham, is the editor of *Automatic and Manual Control*, the proceedings of a conference on automatic control held at the College of Aeronautics, Cranfield, England, in July, 1951.

Contents: (1) Control Systems and the Analysis of Their Behavior. (2) The Inductances and Time-Constants of the Windings of D.C. Machines. (3) The Static Characteristics of Ordinary D.C. Generators, and of Some Simple Combinations, When Separately Excited. (4) The Dynamic Characteristics of Separately Excited D.C. Generators, and of Some Simple Combinations of D.C. Dynamos. (5) Cross-Field and Armature Excited Dynamos: the Rosenberg Generator, the Amplidyne, the Metadyne, and the Magnicon. (6) Machines with Heterogeneous Pole Systems. (7) Some Simple Forms of Feed-Back that are Useful in Conjunction with Sequences of D.C. Generators. (8) Cumulative Feeds-Back, Self-Excitation, and the Three-Field Generator. (9) Unsymmetrical Forms of Cross-Field Machines. (10) Torque Motors and Linear Stroke Motors. Bibliography and References.

MATHEMATICS

Advanced Mathematics in Physics and Engineering. Arthur Bronwell. New York, McGraw-Hill Book Company, Inc., 1953. 475 pp., figs. $6.00.

Chapters of the book are devoted to the development of fundamental principles in the following areas: vibration in lumped and distributed element systems, heat flow, fluid dynamics of both compressible and incompressible fluids, and electromagnetic theory. One of the chapters deals with the various criteria for stability of electrical and mechanical systems, including the Routh-Hurwitz criterion, the Nyquist criterion, and others.

Mathematical topics include infinite series: Fourier series and the Fourier integral; ordinary differential equations; series methods of solving differential equations, including the Bessel, Legendre, and associated Legendre equations; partial differentiation; Lagrange's equations; Hamilton's principle, vector analysis; functions of a complex variable; and Laplace transforms.

Problems have been carefully chosen to supplement the text material with additional information. The author is Professor of Electrical Engineering, Northwestern University.

Numerical Solution of Differential Equations. William Edmund Milne. New York, John Wiley & Sons, Inc., 1953. 275 pp., figs. $6.50.

This book attempts to acquaint the reader with some of the principal techniques available. They are presented in an elementary manner and largely with the aid of examples worked out in minute detail. In order to provide a way around the multiplicity of procedures for numerical solutions, one chapter contains an elementary account, with a minimum of mathematics, of a simple way to solve equations numerically when no great accuracy is needed. This discussion is detailed, and the ideas recur in later chapters. Exercises, an extensive bibliography, and name and subject indexes are included. Dr. Milne is head of the Department of Mathematics at Oregon State College and has been associated with the National Bureau of Standards Institute for Numerical Analysis.

Contents: Part I, Ordinary Equations—Introduction, Elementary Numerical Solution, Analytical Foundations, Methods Based on Numerical Integration, Methods of Runge-Kutta, Methods Based on Higher Derivates, Systems of Equations, Higher-Order Equations, Two-Point Boundary Conditions. Part II, Partial Equations—Explicit Methods, Parabolic and Hyperbolic Equations, Linear Equations and Matrices, Implicit Methods, Elliptic Equations, Characteristic Numbers. Appendixes: Round-Off Errors, Large-Scale Computing Machines, The Monte Carlo Method.

PHOTOGRAPHY

High Speed Photography, Its Principles and Applications. George A. Jones. New York, John Wiley & Sons, Inc., 1952. 311 pp., figs., illus. $6.50.

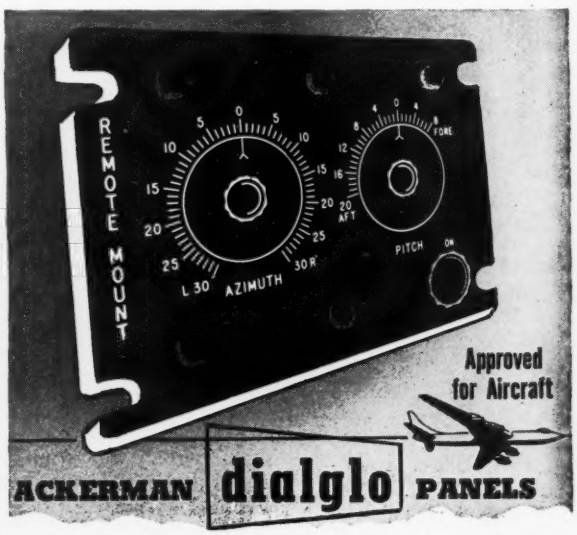
This textbook is presented in an endeavor to summarize the fundamentals, the current practice, and the scope of high-speed photography. It is directed to those engaged in research and development and to those interested in modern methods of machine performance analysis. To keep the book within a reasonable size, only the outlines of equipment design, technique, and applications have been given, except in certain cases not already adequately covered in the literature. For those requiring the full detail, extensive bibliographic references are given at the ends of chapters. The references cited total close to 500. Furthermore, the book contains 118 illustrations. Appendixes give technical information dealing with high-speed cameras, gas-discharge flash tubes, and developers and an index of names and subjects. Among the photographs reproduced in this work are those issued by the Chief Superintendent of Armaments Research, Great Britain; the N.A.C.A.; National Physical Laboratory of Great Britian; National Research Council of Canada; The Royal Aircraft Establishment; and the U.S. Army Office of Ordnance.

Contents: Chapter I, Introduction and History. Chapter II, The Production of Short Flashes. Chapter III, High Speed Cinematograph Camera Design. Chapter IV, Photographic Materials. Chapter V, High Speed Still Photograph. Chapter VI, High Speed Cinematograph Cameras. Chapter VII, Cinematographic Technique. Chapter VIII, Trace Recording Cameras. Chapter IX, Picture-Making Recording Cameras. Chapter X, Scientific Applications of High Speed Photography. Chapter XI, Industrial and Commercial Applications.

PRODUCTION

How to Control Production Costs. Phil Carroll. New York, McGraw-Hill Book Company, Inc., 1953. 272 pp., figs. $5.00.

In showing step by step how to apply effective control procedure, the author emphasizes five factors: accurate sales forecasts; controlling production to know deliveries, to reduce inventory, and to shorten the process cycle; saving excess finishes and tolerances; using incentives; and reporting results promptly. The first chapter deals with the necessity of control of production costs. The other 25 chapters describe in detail a means of accomplishing control with diversified products. The author, who is a consulting industrial engineer, has written this book for men in the management group as well as for those in accounting.



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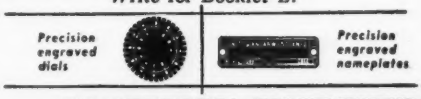

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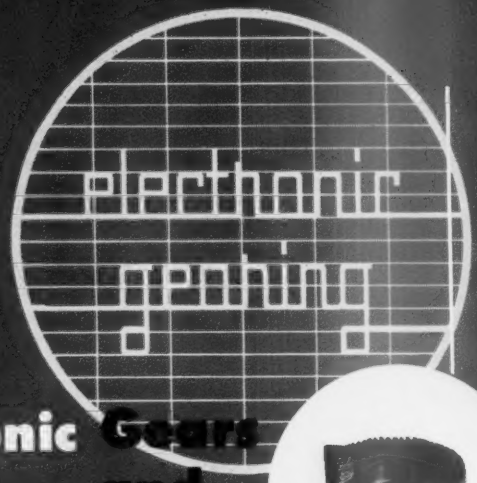

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Personnel Opportunities

This section is for the use of individual members of the Institute seeking new connections and organizations offering employment to Aeronautical specialists. Any member or organization may have requirements listed without charge by writing to the Secretary of the Institute.

Wanted

Engineers—Opportunities for employment exist in the Bureau of Aeronautics, Department of the Navy, Washington, D.C. **Aircraft Modification Design Engineer**—GS-12, $7,040 per annum. Determine remedial measures for structural failures of naval aircraft through analysis of accident and structural failure reports; initiate and follow through corrective actions and design changes. **Electronic Engineer (Radio)**—GS-12, $7,040 per annum. Plan, initiate, and supervise research, design, development, and tests and recommend engineering action concerning landing aids for naval aircraft. **Electronic Engineer (Radio)**—GS 12, $7,040 per annum. Responsible for the planning and execution of a subprogram of research, development, and test projects in a part of the interference reduction field which deals mainly and directly with radio frequency circuitry. **General Engineer (Fuels, Lubricants, and Packaging)**—GS-12, $7,040 per annum. Initiation and planning of effective programs for Navy-Air Force Engineering standardization in the petroleum materials area. Determination of interservice needs, advisory duties to industry, the preparation of basic engineering specifications, and the promulgation of necessary standardization procedures. **Chemical Engineer**—GS-12, $7,040 per annum. As section head, is responsible for the development, evaluation, and service application of fuels, internal coolants, fuel additives, and lubricants for reciprocating, turbojet, gas-turbine, ram-jet, and pulsating-jet aircraft engines. **Electronic Engineer (General)**—GS-12, $7,040 per annum. Design and development of equipment and the prosecution of all activity pertaining to automatic radio-frequency mid-course guidance equipment as applied to pilotless aircraft and guided missiles. **Aeronautical Power Plant Research Engineer**—GS-12, $7,040 per annum. Development of general designs and studies of reciprocating, turbojet, turboprop, ram- and pulse-jet, and rocket engines to be used in subsonic and supersonic land and carrier-based aircraft and guided missiles. Requirements: 3½ years of professional engineering experience in addition to degree. **Aircraft Performance Engineer**—GS-11, $5,940 per annum. Make comprehensive investigations and mathematical calculations of the performance characteristics of aircraft. Compile and issue performance charts for all types Naval Aircraft. **Aeronautical Development Engineer (Hydrodynamics)**—GS-11, $5,940 per annum. Under general supervision performs highly specialized aeronautical engineering work in the field of hydrodynamics in connection with design of naval aircraft; assists in model and full-scale research and development projects in hydrodynamics for improvement of seaplane operation. Requirements: 2½ years of professional engineering experience in addition to degree. Applications may be submitted on Standard Form 57, Application for Federal Employment, to the Department of the Navy, Bureau of Aeronautics, Personnel Division, Attention PE-202, Washington 25, D.C. The Standard Form 57 is available at U.S. Post Offices or may be obtained by writing to the Personnel Division, Bureau of Aeronautics. Visitors to the Washington area may call at Room 3909 of the Main Navy Building, 19th and Constitution Ave., N.W., Washington, D.C.

Associate Professor or Professor—Aeronautical Engineering Department has need of a qualified man to develop the graduate program. Duties include counseling and guidance of students working for the Master's degree and the teaching of graduate and senior courses. Prefer a man with Ph.D. and training and experience which would qualify him to teach theoretical aerodynamics, stability and control, high-speed aerody-

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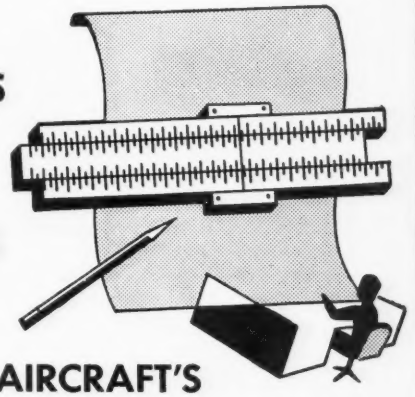

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namics, and related subjects. Salary and rank dependent upon qualifications. Excellent research facilities. Wide interest in the graduate program on the part of employed in the large local aircraft industry. Inquiries should be sent to: Professor M. H. Snyder, University of Wichita, Wichita, Kan.

Aeronautical Design Engineer—GS-11, $5,940 per annum. Duties: Technical supervision and coordination of Coast Guard aircraft acquisition, construction, and improvement program; preparation, study, and evaluation of specifications; initiating changes in design to conform with needs of Coast Guard; resolution of engineering and production conflicts; correspondence and reports. Requirements: A full 4-year professional engineering curriculum leading to a bachelor's degree in an accredited college or univiersity plus 2½ years of aeronautical engineering experience that must have demonstrated a good knowledge of engineering principles and the ability to perform engineering work under only general supervision. Address replies to: Chief, Civilian Personnel Division, U.S. Coast Guard, Room 3006, 1300 E. Street, N.W., Washington 25, D.C.

Aeronautical Engineer-Teacher—The Test Pilot Training Division of the Naval Air Test Center has an opening requiring the services of a highly competent aeronautical development engineer and teacher. His work will include teaching approximately 1 hour a day, as well as work on development projects in the fields of performance and stability and control of transonic and supersonic aircraft. Ample opportunities are provided for individual effort and original thinking. Working conditions are ideal. Low cost Government housing is guaranteed. Present work week is 40 hours, and salary is $7,040 per annum. Civil Service rating GS-12. If you feel that you might be able to fill this job, please contact Mr. D. O. Dommasch, Chief Engineer, Test Pilot Training Division, Naval Air Test Center, Patuxent River, Md. Your letter should include a brief summary of your past experience. Interviews will be arranged as necessary.

Engineers—The Special Devices Center, Port Washington, N.Y., is a field laboratory of the Office of Naval Research which conducts research and development relating to all manner of synthetic training devices including training aids, calculators, demonstrators, research tools, and components thereof. Projects include armament, computers, flight, human engineering, navigation, radar and communications, subsurface problems, visual design and training, and utilization. Vacancies frequently recur for engineering personnel in the fields of electronics, mechanics, and aeronautics. Vacancies currently exist for Electronic Engineers at $5,058 per year. The qualifications for these positions are an engineering degree and 18 months' professional experience of which 6 must have been in electronics.

473. Technical Assistant to Sales Manager—Metropolitan area manufacturer of AN parts offers excellent opportunity for upper-level liaison job with sales staff, requiring capacity to analyze industry problems and requirements with relation to manufacturer's products and to supervise development of new parts to meet these requirements by manufacturer's engineering department. Requires graduate Aeronautical Engineer with several years' air-frame design experience, preferably in structures, as well as some additional experience in production engineering or liaison between design engineering and production.

471. Chief of Stress—Rotary-wing aircraft experience. Responsibilities include static and dynamic analysis on high-speed rotorcraft. Minimum experience 5 years; knowledge of C.A.A. and Military requirements necessary. Work on an expanding program with an established company; location Philadelphia area.

470. Staff Aerodynamicist—Minimum B.S. degree in aerodynamical engineering or physics. Field aerodynamics including the ballistics of free-falling objects. Experience in carrying out experiments in wind tunnels, and experience in optimum shapes on guided missiles. Experience: Minimum of 10 years in responsible position involving research and development. Duties: Perform liaison work between other branches of a technical division. Coordinate data with background knowledge to perform critical analysis and evaluation of research and development program.

468. Aircraft Estimator—Growing southwest air-frame manufacturer has opening for engineer with estimating experience. Minimum of 4 years' aircraft experience is required, preferably in detail and contract estimating. Engineering degree is desirable. Management potential is necessary. Examinations will be given to qualify applicants prior to hiring. Excellent future possibilities. Salary commensurate with qualifications.

467. Aeronautical Engineer—To act as project engineer on wind-tunnel tests and development contracts in a modern subsonic laboratory. Operated by a large eastern university with facilities for graduate work. Applicant should have Bachelor's degree in Aeronautical Engineering and 1 or 2 years of aeronautical experience. Salary dependent upon background.

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Microwave & Electronics Engineer or Physicist—with six to ten years' experience to carry out research and development on guided missiles. The applicant must have experience in planning and directing the work of junior scientists.

Servo-Mechanisms Engineer—to carry out research and development on guided missiles. Experience with electrical and electro-hydraulic servo system and with navigation equipment desirable.

Electrical Engineer or Engineering Physicist—with experience in electronic computation to carry out development work on aircraft fire control computers—basic knowledge of microwave and servo-mechanisms desirable.

Electrical Engineer or Engineering Physicist—to direct electronic designs and electronic systems production engineering for guided missile development. The applicant must have experience in electronic component testing and subminiaturization techniques, and must be capable of directing the work of junior scientists.

Electronic Instrumentation Engineer—to carry out instrumentation work on guided missiles—telemetering and range instrumentation experience desirable. The applicant must be capable of planning and directing the work of junior scientists.

Mechanical Engineers—with six to ten years' experience to carry out design and development on armament systems. The applicants must have experience in planning and directing the work of junior scientists.

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Applicants may obtain application forms by writing to:

Post Office Box 1427,
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The number preceding the notices represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.

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472. Aeronautical or Mechanical Engineering Professor.—B.S. in A.E., M.S. in M.E. Available for September appointment in college or university located in the South or Southwest. Principal fields of interest—aerodynamics, fluid mechanics, and thermodynamics at either undergraduate or graduate level. Opportunities for research should be available in the above fields.

469. Aeronautical Engineer—Ph.D. degree. Ten years' teaching experience and 5 years' industrial experience. Desires teaching position

466. Quality Control Executive—M.E., age 35. Two years' high-level Air Force quality-control experience and extremely diversified aircraft engine and accessories background, including installation engineering, flight test, design, service, and field contacts. Well versed in both theoretical and practical aspects of statistical analysis as applied to quality control and in developing systems and techniques for quality assurance. Well acquainted with military quality-control procedures and requirements. Desires responsible position in aircraft engine, air-frame, or related industry. Complete résumé on request. Available July 1.

464. Design Engineer—B.S. in Aero. Engrg. Twelve years' practical experience; 9 patents; desires opportunity to use inventive ability.

463. Aeronautical Engineer—Turkish engineer, M.S. of Aero. E. Age 34, unmarried, interested in returning to United States or Canada. Ten years' aerodynamic experience including 1 year of confidential work in major United States aircraft manufacturing concern. Five years of aerodynamic work leading to chief aerodynamicist position in Turkish aircraft factory. United States experience includes work on jet bomber. More than 2 years on faculty of principal Turkish technical university. Delivered theoretical aerodynamics paper before 1952 International Mechanics Congress. Prefers aerodynamic research in university. Can present United States professional and character references.

462. Technical Writer—Aviation Consultant; 18 years' experience. All phases including planning, operations, and maintenance, both private and air-line. Can set up factory, maintenance, or flight operations. Majority of experience with aviation training facilities both flight and ground and air-line and private; consultations invited. Successfully doing technical manuals, training manuals, and equipment manuals at home. This saves the cost of man on hand at all times. Not available to move from present position but inviting inquiries to do part-time work on above at home.